NPS-57LN70071A

United States
Naval Postgraduate School

A SIMULATOR EVALUATION OF PILOT PERFORMANCE AND ACCEPTANCE OF AN AIRCRAFT RIGID COCKPIT CONTROL SYSTEM

by

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15 July 1970

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ABSTRACT:

A ground-based simulator facility employing a two-axis compensatory tracking task with a random appearing signal was used to evaluate the performance of one hundred five pilot and non-pilot test subjects using four separate control sticks -- two moveable and two rigid. Pilot acceptance of the rigid cockpit controllers was determined by comparing individual pilot ratings of the sticks. In general, in both performance and opinion, the rigid systems were found to be superior to their moveable counterparts. Steps were taken to avoid errors due to pilot bias, learning, fatigue, or adapation. The results obtained are subject to several test limitations, including the low stick-force levels employed, the lack of aircraft vibration effects, and the realism of the simulation.

This task was supported by: Navy Department, Naval Air Systems Command Air Task A31310/551/70R0050101

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I. INTRODUCTION

It has been traditional for aircraft to have cockpit control sticks that move in a certain direction a given amount in order to impart movement to the control surfaces. This type of control has evolved from the low complexity system where the control stick is directly connected to the control surfaces (reversible control) so that stick deflection is a direct measure of control surface deflection. On modern, high-speed aircraft, however, the forces required to move the control surfaces may exceed the physical capability of a human pilot and some form of powered or power-assisted control system is necessary. In fully powered control systems, there is no direct force or position coupling between the pilot's control stick and the control surfaces, and any cockpit indications must come from 'artificial' feedback signals.

As the simple mechanical control systems of the past are replaced by complex linkages and fully-powered or power-boost controls, numerous problems concerned with flight control system weight, nonlinearities, friction, hysteresis, inertia and backlash arise. These problems, together with the increased reliance on stability augmentation, have stimulated investigations of electronic control systems (fly-by-wire). Fly-by-wire research has now advanced to the point where test flights are being made and favorable and reliable results are being reported. (Ref. 1).

The change from mechanical to electrical control systems offers various possibilities for a cockpit controller that is different from the conventional, deck-mounted moveable stick. Numerous manipulators have been studied, the most prominent of which is a side-located, limited motion hand controller (Refs. 2,3,4,5,6). These systems allow increased cockpit space for flight displays or for additional control functions and depend, for the most part, on a reliable fly-by-wire capability.

The most important parameter when considering different control sticks is that of the aircraft handling qualities. The pilot regards stick feel as a most valuable cue (Ref. 7). Due to the irreversibility of power-assisted electronic flight control systems, this feel must be provided artificially to the stick - whether center or side mounted. Inasmuch as the pilot relies heavily on this stick force, the actual motion of the controls is of much lesser importance. In fact, it is widely recognized that, except possibly during the landing flare, the pilot seldom, if ever, knows the position of his control stick. (Ref. 4,8). This suggests that a force-only (rigid) controller could be applicable to a fly-by-wire control system. Such a rigid stick might prove more satisfactory, if not for primary control, as a back-up precision tracker to be used for formation flying, terrain avoidance, weapon control and delivery, carrier landings, or ground controlled approaches. Such a back-up system may also prove highly valuable in the case of mechanical failure or combat damage to the primary control system.

Limited investigations have been made of rigid sticks (Refs. 4,9,10,11,12,13,14), but the reported results have been contradictatory and essentially inconclusive.

Inasmuch as handling qualities are inevitably determined from pilot opinion, a simulator facility was developed to permit the evaluation of rigid control sticks by comparing them to similar conventional, moveable sticks. This simulator, called a Research and Educational Device for Basic Aeronautics (RED BARON), employs a two-axis, compensatory tracking task with a repeatable, random-appearing signal. This investigation used this simulator to measure pilot performance for one hundred five test subjects on each of four control sticks - two moveable and two rigid. This performance was compared with individual pilot ratings of the separate controllers. Personal pilot experience was collected to insure a thorough test subject analysis. Scores were also recorded during a portion of the test runs to determine the effects on the data, if any, of pilot learning, adaption, or fatigue. An approximate human transfer study was conducted using two sticks and two subjects for the purpose of correlation. Additional qualitative comments from the test subjects were recorded and a statistical score-to-rating correlation study was made.

II. SIMULATOR FACILITY

The simulator facility (RED BARON) designed and built for this evaluation has as its major components a Cathode Ray Tube display (oscilloscope), an analog computer, an electronic counter, a low-frequency function generator, a tape deck, a two-channel visual recorder, an electric timer, a cockpit environment housing, and interface equipment. An equipment listing is contained in Appendix D.

Figure 1 shows the overall view of the simulator cockpit environment housing which was constructed on a 96" x 34" base on which was mounted a salvaged FJ aircraft ejection seat. A cover was constructed over a frame to create an aircraft cockpit environment. The CRT display was mounted in the windscreen area to give the required visual reference for the tracking problem. Figure 2 shows a partial internal view of the cockpit with the lower portion of the CRT (without the cover panel), the pilot's seat and the rigid stick visible.

The tape recorder provides a repeatable testing signal which is displayed on an X-Y CRT with a five inch grid. The pilot-operated control stick generates a signal which, when amplified, acts to cancel out the random input signal from the tape, moving the displayed pip towards the center of the grid. The control signal is altered in the analog computer to simulate actual aircraft dynamics. Thus, in his efforts to center the pip on the display, the test subject has a constant display of the error signal.

A ventilator fan, which is activated by the closing of the entrance door, was installed to cool the simulator cockpit. In addition, a small fan was mounted in the windscreen area to cool the CRT assembly.

The test subject could correct for parallax by using the horizontal and vertical position knobs on the display console (Fig. 3) to center the pip under the mid-grid lines. The Airspeed Indicator shown in Figure 3 and a throttle assembly were not used during this evaluation.

Green and blue indicator lights were installed on the display console above the CRT (Fig. 3). The green light indicates when the target pip is in the scoring area (Scorer) and the blue light indicates when the electronic counter circuit is energized (Timer). These lights are duplicated for the facility operator on the Control and Switching Panel (Fig. 4).

The RED BARON has wiring installed for connection of the four control units so that any stick, when plugged in, will be connected to the output terminals when the stick selector switches on the Control and Switching Panel are in the proper position. A toggle switch selects Moveable or Rigid stick systems and a four-position rotary switch selects the desired control stick.

The two 12-wire bundles from the stick selector switch are identical. One is routed to the side-arm controller arm rest and the other goes to the deck-mounted stick area. At the end of each wire bundle is a sixteen connector plug which has twelve positions (Fig. 5) as follows:

1. Common junction of strain gage terminus (longitudinal)
2. Forward strain gage terminus (longitudinal)
3. Aft strain gage terminus (longitudinal)
4. Moveable stick output (longitudinal)
5. Common junction of strain gages (directional)
6. Left strain gage terminus (directional)
7. Right strain gage terminus (directional)
8. Moveable stick output (directional)
9. Plus five volts (longitudinal)
10. Minus five volts (longitudinal)
11. Plus five volts (directional)
12. Minus five volts (directional)

No rudder pedals or facsimiles thereof were installed inasmuch as this was to be a two-axis problem and because rudder is seldom used in single-engine jet aircraft in the cruise configuration.

An overall view of the facility, including some of the circuit wiring between system components is shown in Figure 6.

III. CONTROL STICKS

Four different control sticks were constructed for use in this evaluation. Two of the sticks were of the conventional moveable type using variable potentiometers as signal generators. The other two sticks were constructed as rigid types using strain gages in a Wheatstone Bridge circuit as the signal generators.

One of the rigid sticks and one of the moveable sticks were made as deck-mounted types and the other two sticks were made into side-arm controller units.

MOVEABLE DECK-MOUNTED STICK

The major components of the moveable deck-mounted stick were salvaged from a North American FJ aircraft These parts, consisting of the stick proper, pitch and roll fulcrums, and lever arms were mounted on a plywood base. See Figure 7. The height of the stick from the base is 25 5/8" with a moment arm of 22" in the pitch direction and a moment arm of 16" in the roll (lateral) direction. An artificial feel system was installed to develop a stick force in proportion to stick displacement simulating the control feel of a jet aircraft. This artificial feel is provided by springs mounted in both the fore and aft direction and in the lateral direction. No bobweights were used. Two variable potentiometers were mounted on the control unit, one to generate pitch signals, and one to generate lateral signals. The variable potentiometers are of the one-turn type driven by a 1:4 ratio gear drive from the stick. The gearing between the stick position and the simulated control surface deflection is a linear relationship even though the majority of powered control systems employ a non-linear gearing such that a relatively greater stick deflection per control deflection will occur at the neutral stick position. Plus and minus five volts are the inputs to the potentiometers and the output signals are the simulated position indicators of the control surfaces. These outputs become the inputs to the switching circuit shown in Figure 5, (for clarity, only the moveable hand stick circuit is shown) and thence into the analog circuit shown in Figure 12.

The plywood base fits snugly under the cockpit simulator seat to provide a solid platform for the operation of the stick. The input and output wires are attached to a sixteen connector plug which permits the rapid change of control sticks.

MOVEABLE HAND STICK

The moveable hand stick, as shown in Figure 8, was mounted on a quarter inch aluminum box, 3" x 4" x 14" which contains the lateral variable potentiometer and the lateral articial feel springs. The pitch potentiometer and the pitch feel spring are monted externally and forward of the control box. The pitch and yaw potentiometers have a 1:4 gear ratio with the output from the plus and minus five volt input fed to the switching circuit as shown in Figure 12. As in the moveable deck-mounted stick, the motion of the hand grip is linear in relation to the simulated control surface deflection. The control unit is mounted on Velcro fabric for a quick change capability with the rigid hand stick. The input and output wires are attached to a sixteen connector plug to permit the rapid change of control sticks.

RIGID DECK-MOUNTED STICK

The rigid deck-mounted stick was constructed from a salvaged helicopter stick, cut down to a size comparable to the moveable stick and mounted on an aluminum flange. See Figure 9. The flexure, shown in Figure 13a, was machined from one-inch diameter 2024-T4 Alcoa aluminum stock. This material has an ultimate tensile strength of 68,000 psi and a yield strength of 47,000 psi at a temperature of 75° F. (Ref. 15).

It was desired to have the maximum bending stress of the flexure approximately one-half of the yield stress in order to provide the maximum possible signal, yet to be well within the yielding point of the 2024 aluminum. Assuming a moment arm of approximately two feet, computed from the top third of the control grip to the center of the flexure, and a maximum applied force of 15 pounds, the moment becomes 360 inch-pounds. The formula

$$S_{max} = \frac{M_c}{I} \qquad \frac{M}{bh^2/6}$$

was used to calculate the thickness, h = 0.3 inches. An S_{max} of 24,000 psi and a 'b' of 1" was used for this calculation.

Four SR-4 strain gages, type FAB-25-12513, were attached, as shown in Figure 13a, by Eastman 910 cement and then waterproofed. The strain gages have a gage factor of 2.07 $\pm$ 1%, resistances of 120.0 $\pm$ 0.2 ohms, and were designed to be temperature compensated for aluminum.

The strain gages were used as two resistances in a Wheatstone Bridge that was energized with 10 volts. With this circuitry, the bending moment applied will cause the voltage changes in the two strain gages to be additive while cancelling the effects of a moment applied at right angles to the flexure. (Ref. 16). The Wheatstone Bridge arrangement is shown in Figure 5.

The flexure was pressed into a six inch square piece of 3/4" aluminum which was then mounted on a plywood base. A strain gage guard of three inch aluminum thin-walled tubing was installed around the flexure area to protect the delicate strain gages and wiring. The attached wires were connected to a sixteen connector plug for quick change capability.

RIGID HAND CONTROL STICK

The rigid hand control stick was mounted on an aluminum control box similar to that of the moveable hand stick. See Figure 10. The aluminum flexure, as shown in Figure 13b, was constructed of material identical to that of the rigid deck-mounted stick, but the thickness of the flexure was reduced to 0.15" which resulted in a maximum stress of 25,000 psi, computed for a force of fifteen pounds on a moment arm of six inches. This compares closely with the 24,000 psi of the deck stick maximum stress computed using a force of fifteen pounds on a 24 inch moment arm.

Strain gages identical to those used on the deck stick were attached and similar wiring, plugs and circuits were used. For clarity, Figure 5 shows only the switching and

Wheatstone Bridge circuits for the rigid hand stick.

The hand grips for the hand controllers were made from an epoxy mixture of five parts APCO 210 Resin and one part APCO 180 Hardener with carbon lampblack added for color. The knurled sections of the handles were cast in molds, as shown in Figure 11, which had been made using a clay hand grip model.

IV. ANALOG COMPUTER CIRCUIT

The inputs to the analog computer are from the Control and Switching Panel of the simulator, Figure 4, through a patch panel box and a multi-wire extension. The outputs from the C & S Panel come from either the variable potentiometers of the moveable controls or from the output terminals of the strain gage Wheatstone Bridge circuits of the rigid sticks.

The selection of the stick inputs depends on the switch positions on the simulator C & S Panel. In order to change these inputs, a toggle switch is used to select either moveable or rigid systems and a rotary switch is used to select one of the four sticks. The toggle switch provides for both changes in the analog input resistors (2,000 ohms for rigid sticks, 100,000 ohms for moveable sticks) and feedback resistors (400,000 for rigid sticks, 100,000 ohms for moveable sticks). These resistor values give an amplification factor of one for the moveable and two hundred for the rigid sticks.

The signals are then passed through an additional amplifier to increase the amplitude by a factor of ten before the signals enter the longitudinal and directional control circuits.

The circuit used to amplify the signals and to simulate aircraft response is shown in Figure 11. The longitudinal circuit approximates the Short Period motion of an F-4 aircraft at 0.9 Mach at sea level. The output is considered to be the pitch angle, θ, effected by the dynamic short period mode. Figure 14 shows the analog computer output after a step longitudinal input is introduced into the system. In the short period approximation, since the airspeed is constant, the elevator input results in a Θ change, the magnitude of which is step input time dependent. In addition, the Θ change, as shown in Figure 14, will remain in the circuit until removed, due to the lack of airspeed and/or altitude change with any elevator input. (Ref. 17).

The lateral circuit is an approximation of an aileron input to a stable aircraft. The response to a step input is shown in Figure 15. Reference 18 states that the majority of pilots prefer a system where the aileron is bank-ordering so that a steady aileron force is required to maintain a steady bank angle. In the simulator analog circuit, a step input in the lateral mode, as shown in Figure 15, will return to the null position after the input is removed

V. ANALOG TIMER CIRCUIT

The scoring principle used in the simulator is based on timing the periods when the display pip is within a predetermined scoring area on the CRT display. The test subject, using the control stick, attempts to cancel out the prerecorded taped inputs so as to center the pip on the grid. The longitudinal error signals and the directional error signals are summed independently and then amplified by a factor of ten, as shown in Figure 16. The amplified signals are passed through a sign changing amplifier, and both the original signal and the signal with the reversed sign are fed to diodes which allow current flow in only one direction when a selected voltage is exceeded.

The increase in signal magnitude is required to activate the diodes which require a minimum of one-half volt before passing current. The sign changing amplifiers are necessary so that both plus and minus signals will trigger the comparator, which is biased for signals of but one polarity.

A bias of -0.5 volts is patched to the output side of the diode bus so that when any summed, amplified signal exceeds this level the diodes will permit current flow to the signal comparator input 1N1 terminal. An input of -0.75 volts is patched to the 1N2 terminal of the comparator to provide a comparator bias signal base. The 1N2 input may be varied to adjust the size of the CRT display scoring area.

The comparator relay connects the output of a ten hertz oscillator to the electronic counter so that when the summed signals (either longitudinal or directional) exceed a specified level, the oscillator signal to the counter ceases. Since the counter records the ten hertz oscillations, the electronic counter records the time that the summed signals (both longitudinal and directional) are within the scoring area to the nearest tenth of a second.

A switch on the C & S Panel permits the starting and stopping of the counting sequence.

The comparator relay also activates the Scorer light on the cockpit display panel and the C & S Panel to advise when the signal pip is within the scoring area.

VI. TESTING PROCEDURE

Before the beginning of each test run, the subjects were briefed as to the operation of the simulator and the testing plan. Explanations were given as to the nature of the sticks, the size of the scoring area, and the control motion and/or force required to produce a given pip deflection. In addition, the meaning of the Scorer and Timer lights, the testing order of the sticks, and the testing run length was explained.

The test was initiated by selecting the proper stick switches on the Control and Switching Panel and turning on the tape drive. The first two-minute segment of the tape input was a zero signal to permit the balancing of the potentiometers of the analog circuit (centering the scoring area on the grid) and to allow the test subject to correct for parallax by centering the pip.

The input signal for the test run was programmed as follows:

1. Two minutes of zero signal.
2. One minute of longitudinal signal only.
3. Thirty seconds of zero signal.
4. One minute of directional signal only.
5. Thirty seconds of zero signal.
6. One minute of combined longitudinal and directional signal. (Practice run).
7. Thirty seconds of zero signal.
8. Three minutes of combined longitudinal and directional signal. (Scoring run).

The test subject was informed when the test signal changed modes and was allowed a thirty second rest period (zero signal) between each mode. Adequate warning was furnished prior to the start of the scoring run and the test subject was notified when one minute remained in the scoring run.

At the end of the scoring run, a changeover switch was made to another stick and the testing process was repeated until each of the four sticks had been used utilizing the identical input signal.

At the conclusion of the test, the subjects were asked to complete a questionnaire evaluating the control sticks and providing precise information concerning their total flight experience. These evaluations were made before the scores were disclosed. The questionnaire used is shown in Table 1.

In order to make an adequate evaluation of the controllers, a suitable rating scale was required. In the past, handling qualities research has usually employed the standardized Cooper Rating scale (Ref. 19), or, more recently, the modified Cooper-Harper scale (Ref. 20). Preliminary testing during a "shake-down" period disclosed that a finer discrimination was needed than was available with the standardized scales. Therefore, a new rating scale was devised (Table 2) which allows for a wider range of "satisfactory" ratings, while still providing the opportunity for assigning an adverse opinion.

The preliminary testing also disclosed a tendency for the test subject's performance to improve slightly as the test progressed from one stick to another. For this reason, the testing order was varied in an effort to cancel, or at least minimize, the learning function effects. Inasmuch as the primary purpose of the study was to compare rigid to moveable sticks, the variation of test order was concerned only with

TABLE 1

PILOT QUESTIONAIRRE

Name ____________ Test Number ____________

Age ______ Date ________

- -

FLIGHT EXPERIENCE

Approximate Number of Pilot Hours in:

Single-Engine Jet	________
Multi-Engine Jet	________
Single-Engine Prop	________
Multi-Engine Prop	________
Helicopter	________
Light General A/C	________
Non-Pilot	________

Type of Operational A/C With Most Experience (F-4, A-4, etc.)

____

Type of Operational A/C With Most Recent Experience.

____

How Long Since Piloted Any Aircraft? (If over one month)

____

How Long Since on Full-Time Operational Flight Status?

____

- -

PILOT OPINION AND PERFORMANCE

	Pilot Rating	Test Score	Preference
Moveable Center Stick	________	________	________
Moveable Side-Arm Stick	________	________	________
Rigid Center Stick	________	________	________
Rigid Side-Arm Stick	________	________	________

TABLE 2

PILOT RATING SCALE

(Numerical Rating - Descriptive Phrases)

1. Fantastic, could not be improved. Should be in all A/C.
2. Excellent control response, no gripes.
3. Good response, pleasant to fly.
4. Good response, would require some getting used to.
5. Satisfactory response, would expect no difficulty.
6. Satisfactory, would expect minor problems at times
7. Acceptable, but with some unpleasant characteristics.
8. Unacceptable for normal operations
9. Unacceptable for any operations.
10. Unsatisfactory, dangerous, uncontrollable.

alternating the rigid and moveable pairs In each pair of systems, the center-mounted stick was used first.

To determine any possible learning, adaption or fatigue effects during the tests, partial scores were observed and recorded at thirty second intervals for thirteen of the test subjects. Finally, qualitative comments by the test subjects concerning the validity of the simulation and the applicability of the rigid stick concept were encouraged.

VII. ANALYSIS AND CLASSIFICATION OF TEST SUBJECTS

To properly interpret the data in a test of this type, it is necessary to have background information on the test subjects. The flight experience data obtained from the test subjects' questionnaires are shown in tabular form in Appendix A.

Included in the one hundred five test subjects were Naval Aviators, Naval Flight Officers, private pilots and non-pilots representing a broad spectrum of aircraft flight experience. The private pilots and non-pilots tested can be considered, in general, as representative of the type of personnel who enter Naval flight training.

PILOT CLASSIFICATION

To facilitate an interesting and meaningful evaluation of the scores and ratings, the test subjects were classified into five major groups:

1. Jet (JET) Pilots 31.0%
2. Propeller (PROP) Pilots 24.2%
3. Helicopter (HELO) Pilots 15.5%
4. Private (PRI) Pilots 13.8%
5. Non-pilots (NON) 15.5%

It can be seen that a relatively even distribution was obtained, there being enough subjects in each category to insure an accurate data base. Three subjects had significant experience in two different categories and were therefore included in both. The classification of each subject is shown in Appendix B.

This division of skills was made for several reasons. First, it was felt necessary to evaluate the opinions and performance of the subjects in light of their previous experience. Different types of pilots use different control sticks. In general, the jet and helicopter pilots are experienced with the conventional, deck-mounted moveable control stick, while propeller and private pilots use yoke or wheel controllers. Single engine propeller aircraft pilots do use the center-mounted control stick, but only two subjects (former T-28 flight instructors) had the majority of their experience in aircraft of this type. Second, pilot classification of the data could provide some indication of the type of aircraft in which a rigid stick might be most applicable. For example, if the jet pilots preferred a rigid stick system, this type might be more readily installed in jet aircraft. Finally, the performance and evaluation of non-pilots as compared with that of the pilots is required to determine the effect, if any, of long-established flying tradition on the opinions of the pilots. It should be mentioned, however, that all of the non-pilots did have some limited amount of flight experience, although in most cases this was less than twenty hours.

TEST SUBJECT ANALYSIS

The average age of the test subjects was 27.9 years, with 67.3% between 27 and 32 years of age. A significant difference of 5 to 12 years was noted between the age of the non-pilots (younger) and the pilots

80% of the pilots had flown some type of aircraft within one month of the day they were tested (Combat Readiness Training flying) The average time since any flight was 2.7 months, including five subjects who had not flown for over a year. In general, the private pilots had not flown recently.

The Navy and Marine pilots who were tested were students at the Naval Postgraduate School and not on operational flight status. The average time since these pilots had been on operational flight status was 13 months. 58.7% of the pilots had been on operational status between 5 and 12 months prior to their test. Only nine of the pilots had not flown operationally in over 2½ years.

A wide variety of Naval aircraft was represented in the experience bank of the military pilots. These aircraft included:

JET: A-4, A-6, A-7, F-4, F-8

PROP: A-1, C-121, P-2, P-3, P-5, S-2, T-28

HELO: H-2, H-4, H-24, SH-3

63% of the military pilots had their most recent experience in the same type of aircraft in which they had had the most experience. Only one pilot had significant recent experience in an aircraft of a different type (a Helo pilot in an S-2).

The average military pilot tested had flown 2200 total pilot hours with 86.8% having between 1000 and 4000 pilot hours. The private pilots had significantly less flight experience, with an average of 200 hours apiece.

In general, it may be said that the majority of those tested were moderately experienced military pilots, about 30 years of age, who had been on operational flight status one year previous, and were currently making proficiency flights in the same generic type of aircraft (Jet, Helo, et cetera) at the time of the tests.

VIII. TEST RESULTS

By the end of the testing program, results were obtained from one hundred five subjects, including eighteen non-pilots. The data obtained -- test scores, pilot ratings, and testing order -- are given in Appendix C. Several methods of data reduction and comparison were utilized for a complete and meaningful evaluation of the test results. Average scores and ratings were computed for each pilot classification and for the entire test group. Since averages can give an incomplete, and often erroneous, view, the raw scoring and pilot rating distributions are given to supplement the averaged performance and rating of opinions. In addition to the comparison of the various control sticks, the individual pilot classifications are compared to further illuminate the subject.

AVERAGES

The over-all average test score for each stick (out of a possible total of 180 seconds) is shown in Figure 21. It is evident that the body of the test subjects did better with the rigid controllers than with the moveable sticks. The best performance was on the rigid side-arm stick, while the poorest by far was with the moveable hand controller. The average score with the moveable center-mounted stick, while lower, compared favorably with the rigid systems.

Figure 32 presents the average pilot rating for each stick. The rigid sticks were preferred overwhelmingly over the moveable controls The force-only sticks were found to have "good response", while the moveable controllers were rated only "satisfactory". The subjects tended to dislike the moveable side-arm controller, and little difference was noted between the two rigid sticks. At least on the average, pilot opinion correlated with actual performance. A more detailed score-to-rating correlation study is included in Section IX.

COMPARISON OF STICKS

More detailed comparisons of the four control sticks for particular pilot classes are shown in Figures 19 and 20. These results (Fig. 19) show that all groups did better with the rigid controls to varying degrees. It can also be seen that Jet, Helicopter and Non-pilots exhibit variations in performance identical to those of the overall averages (Fig. 21); i.e., rigid side-arm -- best, and moveable side-arm -- worst. Notable differences are: (1) the Prop pilots did slightly better with the rigid center-mounted stick than with the rigid hand controller, and (2) private pilots scored higher with the moveable side stick than with the deck-mounted moveable stick.

It can be seen from Figure 20 that all pilot groups preferred the rigid to the moveable controls, and disliked the moveable side stick. Opinion was fairly evenly divided as to which stick was the best -- rigid center-mounted or rigid side-arm. The relative magnitudes of all the rating averages are about the same, indicating that the pilots' interpretations of the rating scale was quite uniform.

COMPARISON OF PILOT CLASSES

Actual comparison of the different pilot groups for a particular control stick is shown in Figures 22 and 23 This analysis reveals that private pilots and non-pilots scored higher than pilots with the rigid control sticks. As expected, jet pilots performed better than the other classes with the moveable center-mounted stick due to their previous experience with this type of control The results also indicate that propeller pilots, in general, encounter difficulty with the sidearm controllers, and both prop and helo pilots tended to score below the average on all sticks.

SCORE AND RATING DISTRIBUTION

Charts of the test score and pilot rating distributions were made as a part of the averaging analysis The over-all performance distribution plot of Figure 24 shows the percentage of the total number of test subjects whose final score lay in each five-second time interval throughout the range of test scores. A statistical distribution of scores about the mean is approached with the two rigid sticks and the moveable center-mounted stick (Fig. 24a,b,c). It is to be noted that the moveable side-arm controller results are marked by a rather even distribution of scores concentrated at the lower end of the scale.

The over-all pilot opinions (Fig. 25) are somewhat more divided on the moveable systems than on the rigid sticks -- especially in the case of the moveable hand controller, where the ratings are particularly scattered.

Indentical performance and pilot opinion distribution plots for the different pilot classifications are included in Appendix E. Facts of interest from these graphs are: (1) Jet pilot scores on the moveable side stick were divided into two groupings -- one average and one poor (Fig. E-1d); (2) Two individual prop pilots scored extremely low on the rigid side-arm controller -- lowering the over-all performance average for this classification (Fig. E-3b); and (3) While the scores of the private pilots were concentrated, their opinions of all sticks were scattered -- indicating that perhaps not enough private pilots were tested for a valid comparison (Figs. E-7, E-8).

IX. HUMAN FACTORS INVOLVEMENT WITH TEST VALIDITY

In a test program of this nature, dealing with variations in pilot ability and the vagaries of personal opinion, a great deal of care must be taken to insure validity of the data. Human involvement errors can be introduced by myriad differences in adaption, learning, fatigue and experience, and by fluctuations in attention, motivation and judgement. Safeguards must be established and checks need to be made to cancel or minimize these possible sources of error.

Several methods of analysis were utilized to determine the nature of human involvement. A score-to-rating correlation study was conducted to determine the effects, if any, of pilot bias. A standard regression analysis was applied to the data as a means of representing each score and rating on a single graph. Learning, adaption and fatigue of the test subjects was examined by observing the variation of performance throughout a run, and the testing order of the controllers was varied throughout the tests. Additional information concerning learning and adaption, as well as variations in stick dynamics, was sought by an approximate human transfer function study with the simulator. A check was also made to learn if there was a variation in test results if the magnitude of the pip deflection were changed. This was necessary inasmuch as the pip scale may have been altered during the seven month testing program. Finally, the realism of the simulation was studied by comparing non-pilot performance to that of pilots and by soliciting individual comments from the pilots who were tested

SCORE-TO-RATING CORRELATION

With the introduction of a new device like a rigid control stick, the possibility exists that a pilot could become enhanced with its novelty and evaluate it accordingly. On the other hand, a pilot with many hours experience with a moveable deck-mounted stick might tend to dislike the rigid controls, even though his performance is superior while using them. To determine the magnitude of this type of problem in the testing program, a score-to-opinion correlation analysis was applied. Plotting the over-all average scores versus the average ratings for each stick as shown in Figure 26 gives a first approximation as to how well the pilot opinions correlate with performance. The strong correlation is obvious, since the rating becomes rapidly less favorable (higher number) with decreasing test scores. Similarly, in Figure 27, a regression analysis, plotting score versus rating and reducing the points to a single line for each controller, shows this strong correlation of performance to pilot evaluation.

For a more detailed analysis, an individual correlation factor "r" was calculated for each test subject. These factors are listed in Table 3, with a perfect correlation being r = 1.000. This value of r is derived from the square root of the square to avoid the negative number that would appear due to the fact that the rating scale is inverted. That is to say, a decreasing pilot rating occurs with an increasing rating number. From Table 3 it can be seen that fifty-six of the one hundred five subjects have a high

TABLE 3

INDIVIDUAL PILOT SCORE-TO-RATING CORRELATION FACTORS

Subject	r	Subject	r	Subject	r	Subject	r	Subject	r
1	.912	22	.394	43	.000	64	.935	85	.690
2	.978	23	.546	44	.918	65	.515	86	.952
3	.718	24	.829	45	.941	66	.929	87	.880
4	.972	25	.971	46	.669	67	.835	88	.446
5	.350	26	.642	47	.900	68	.733	89	.387
6	.971	27	.932	48	.993	69	.933	90	.670
7	.460	28	.952	49	.758	70	.956	91	.752
8	.539	29	.994	50	.007	71	.954	92	.325
9	.619	30	.985	51	.914	72	.951	93	.971
10	.911	31	.965	52	.260	73	.749	94	.975
11	.660	32	.926	53	.004	74	.717	95	.873
12	.697	33	.900	54	.532	75	.935	96	.795
13	.978	34	.204	55	.866	76	.979	97	.875
14	.767	35	.453	56	.741	77	.826	98	.529
15	.804	36	.576	57	.796	78	.430	99	.873
16	.746	37	.426	58	.812	79	.886	100	.990
17	.948	38	.952	59	.984	80	.981	101	.702
18	.833	39	.149	60	.493	81	.952	102	.945
19	.967	40	.109	61	.307	82	.892	103	.427
20	.206	41	.990	62	.381	83	.844	104	.595
21	.982	42	.803	63	.572	84	.976	105	.976

correlation of .800 or better. Twenty-five percent of the subjects tested have a poor score-to-correlation (below .400). A close examination of the scores and ratings of these subjects reveals the causes of this poor correlation. Twelve of these testees had poor correlation due to their nearly identical scores on the separate sticks. The remaining poor correlations can be laid, at least in part, to pilot bias, as evidenced from the comments of these subjects.

The average correlation for each pilot classification is of interest and is given in Figure 28. As expected, the less-experienced private and non-pilots had significantly lower score-to-rating correlations than those of the military pilots.

Thus, with a high over-all average correlation of .680, it appears that pilot bias had little effect on the data. The majority of the test subjects had relatively high performance-to-opinion correlations. The poor correlations were few in number, and the errors introduced tended to be mutually cancelling.

LEARNING, ADAPTION, AND FATIGUE.

During the preliminary testing it was noted that the test subject's skill appeared to improve as the testing progressed. To avoid the possibility of one type of stick obtaining an advantage over the other, the testing order (moveable versus rigid) was changed for each subject. Fifty-three subjects used the rigid controls first and the remaining fifty-two started with the moveable sticks. Thus any possible learning function effects should have been nearly eliminated. Evaluating the increase in score from the first stick used to the next, the average learning was of the order of one second (0.56% of the maximum possible) and thus essentially negligible.

An almost universal comment from the test subjects upon finishing the test was that the tracking task was extremely tiring. To ascertain further learning, adaption or fatigue factors, partial test scores were recorded at 30-second intervals for thirteen test subjects. The results obtained from this survey are shown in Figure 29. It is evident that the test scores dropped off rather rapidly during the final 30-second time frame. This could be due to the fact that the subjects were given a notification one-minute prior to the end of the run. Motivation may have lowered slightly in anticipation of the completion of a somewhat tedious task.

Little evidence of slow adaption to the controllers can be found from the results. The subjects in general appear to have become fully adapted to each stick during the alloted practice time that preceeded each scoring run. The scores in the first frames show only a slight improvement in performance, with actually a decrease while using the moveable side-arm controller. This is not to be considered as being too surprising since human operator control adaption usually occurs in one to three seconds following a change in simple tracking conditions (Ref. 21).

An effort was made to compute an approximate human transfer function for two test subjects using the RED BARON facility.

It was hoped that a more analytical description of human adaption and learning could be found (Ref. 22). The subjects completed a sinusoidal tracking task in the directional mode at various frequencies of oscillation, using the moveable center-mounted stick and the rigid side-arm controller. Their frequency responses were recorded and are illustrated in the Bode plots of Figures 30 and 31. Pilot transfer functions were obtained from these plots by the asymptotic approximation method. The similar form of the curves are an indication that human response, and thus adaption, is comparable for a given stick; but that the response to two different sticks can be quite diverse. No further effort was made to apply these results to the data since the study was but approximate and since indications of adaptive difficulty in the tests were absent

SCORING PIP DEFLECTION

Since the testing program extended over a several month period, the motion of the pip on the CRT display for a given control force or displacement could quite possibly have been changed. This could have occurred due to alternate usage of the tape deck or actual tape deterioration. Periodic calibrations of the pip were made, but the possibility still existed that the pip motion could have been altered between the calibrations. To check this source of error, three subjects were tested with two different pip deflections -- one larger and one smaller than the norm. As might be expected, the scores with a small deflection were higher as the pip was easier to control. However, little change was found in the relative differences between the four control sticks. Thus it was assumed that even if small changes occurred in the pip deflection, the error, for comparison purposes, was minimal.

TEST LIMITATIONS AND SIMULATION VALIDITY

Most pilots seemed to agree that while their scores and ratings were higher with the rigid systems in the simulator, the situation might be significantly different in an actual aircraft. Herein lies the major limitation to an opinion survey of this sort. It was felt by most of the pilots that actual flight testing would be necessary to determine, for certain, pilot acceptance or rejection of a rigid control stick. The relatively high scores of the non-pilot group cast a further doubt on the realism of the simulation. The age differential between the non-pilots and the pilots could well be a factor in this score spread, however.

Another key limitation concerns the low force gradients incorporated into all four sticks. The maximum force necessary for full scale deflection of the pip was about one pound, while the optimum stick force per g in an actual aircraft is five to seven pounds (Ref. 23). This low force was deliberately introduced into this phase of the testing. It was desired to have the moveable controls nearly force independent so that they would be nearly a motion-only type of system. The rigid controls were rigged for a force that approximated that of the moveable controls for purposes of comparison. A more thorough and comprehensive study should include the effects of variations of stick force and stick force gradients per pip deflection and deflection rate on pilot opinion and performance A throttle and airspeed indicator have been rigged for this purpose, with the throttle controlling the feedback resistances of the analog computer so that increased throttle (as evidenced by increased airspeed indications) results in increased force requirements. This system was not energized during this phase of the testing in order that all those tested could be compared at the same base.

This study was further limited in that the relative effects of vibration were ignored. Aircraft vibration can reduce the manual dexterity of the pilot and introduce an additional unsteadiness in his control motion. The human body tends to damp out vibration; thus problems could arise with the side-arm controllers where the pilot's arm rests on a surface that would vibrate with the aircraft. Reference 1 reported that a moveable control stick gave performance superior to the rigid controller at all exciting frequencies of vibration tested. Vibration would naturally enter a flight test program and could also be introduced into a simulator. An interesting sidelight of vibration effects is the ascertion by several neuro-muscular experts that there is a low frequency neuro-muscular response that, if in resonance with external vibrations, could incapitate the control function of the human operator.

The effects of acceleration on control stick performance should also be investigated in a flight test situation rather than in a ground-based simulator.

During the course of the testing, several pilots expressed concern about the effect on a rigid controller of movement of conventional stick-mounted trim switches and microphone buttons. While these switches normally create no stick motion when operated, they would involve the addition of an extra force on a rigid control stick. Unless unconventional switches were installed, this would mean applying an opposite compensating force when using the trim tabs, to avoid undesired control deflection. This problem could be included in further simulator studies.

A final limitation might lie in the fact that the subjects tested were not trained test pilots as is the custom in handling qualities simulator studies. The limited qualitative nature of the information requested in the evaluation of the sticks, however, should have relieved this requirement, and the high score-to-rating correlation achieved by the test subjects supports this assumption. In addition it was desired to determine the opinions of average fleet pilots with regard to the acceptance of a rigid cockpit control system.

X. DISCUSSION AND CONCLUSIONS

The purpose of this investigation was to determine the acceptability to operational military pilots of a rigid cockpit control system and to evaluate their performance while using force-only controls. Within the restrictive framework of the test limitations mentioned in Section IX, this has effectively been accomplished. Results were obtained from one hundred five flying and non-flying test subjects operating both moveable and rigid controllers in a compensatory tracking task.

To draw specific conclusions from the collected data, it is necessary to thoroughly analyze the test subject group in order to ascertain the applicability of the results. At the same time, particular measurement standards and procedures must be reviewed to insure validity of the test. Finally, in a study involving human opinions, the possible sources of error induced by the subjects and inherent in the test itself must be examined.

The test subject group consisted of Navy and Marine aviators, Naval Flight Officers, private pilots and non-pilots. The pilots who were tested were on proficiency flying status and therefore may not have been quite as sharp as their active fleet counterparts. The non-pilot group was highly represntative of the personnel who enter Naval flight training. A significant number of each pilot classification -- jet, prop, helo, private and non-pilot -- was tested to provide a sound base for significant conclusions. The possible exception was the private pilot class which showed basically erratic performance and ratings, possibly due to the duration of time since many of them had flown, and their relatively low flight experience factor. In general, however, the inexperienced subjects were included in the testing in order to compare their performance with that of the pilots and the opinions of the inexperienced groups were of less importance to the study. The wide variety of aircraft included in the experience of the military pilots represented a majority of the operational aircraft in the fleet today.

The measurement procedures used in this investigation were relatively conventional and the test validity was protected. The use of signal error in a compensatory tracking task is a common measure of pilot performance and is a fairly standard procedure. The revised rating scale, allowing for finer discriminations, was especially devised for this study. It success is evidenced by the relatively uniform interpretations it received by the various test subject classifications.

Numerous precise measurements were conducted to eliminate errors introduced by the human test subjects and the test apparatus. The extensive correlation analysis effectively ruled out test subject bias in most cases. It demonstrated that the small amount of bias found tended to cancel itself out; i.e., although some pilots preferred the moveable system and scored high with the rigid, others preferred the rigid and scored high with the moveable controls. The number of negative correlations was few. Alternating the testing order of the control sticks virtually eliminated pilot learning effect during the course of the test. Even so, the learning value factor was a very small number. Most of the test subjects experienced fatigue during the final 30 seconds of the run; however, this only introduced a difference of about one-half of one percent in the over-all test score. The fatigue was slightly greater with the moveable controls -- another indication of their difficulty. No problem was experienced with test subject adaptation to a particular control stick. The tape segment alloted to practice and familiarization allowed time for nearly complete adaptation. The error due to any possible change in pip deflection was negligible, since the relative differences of scores and ratings for each stick remained essentially constant. These various safeguards and checks greatly minimized the various possible sources of error to the data.

In general, the pilots performed better with the rigid control sticks and preferred them to the moveable systems. The rigid side-arm controller was the consensus favorite in both performance and preference. The moveable side-arm stick was uniformly disliked and its performance was inferior. The moveable deck-mounted stick was only slightly less preferred by the pilots than the rigid systems -- the differences in scores and ratings were not large; whereas the less experienced private and non-pilots displayed a rather marked preference of rigid over moveable controllers with a similar large difference in performance with each system.

These results, as a preliminary indication, suggest that a rigid controller is certainly feasible either as a primary control, back-up control, or a precision tracker in an aircraft with a fly-by-wire capability

It would not be economically feasible to replace present moveable controls with force-only sticks, since the difference in indicated performance and present-pilot rating is not large. Therefore, on the basis of the preliminary results of this study, the rigid control systems appear worthy of further investigation for <u>future</u> primary control systems or <u>present</u> secondary tracking functions.

The major simulation limitations lie in low stick force gradients, lack of vibration (as is found in aircraft), and the absence of acceleration effects. This study should not be considered as a blanket indictment of the moveable side-arm controller. It is extremely possible that the dynamics of the particular model tested contributed to a great degree to its low rating Gravity effects were not included, but there is a possibility that a rigid control system may be superior under high g conditions, due to the difficulties of gross arm motions as would be required with a moveable control.

All of these limitations could seriously affect the pilot performance and acceptance of rigid control systems as reported in this study. However, the derived results indicate a preliminary feasibility, with a strong requirement for future investigation and flight testing.

Figure 1. External Overall View of Simulator

Figure 2. Internal View of Simulator Cockpit

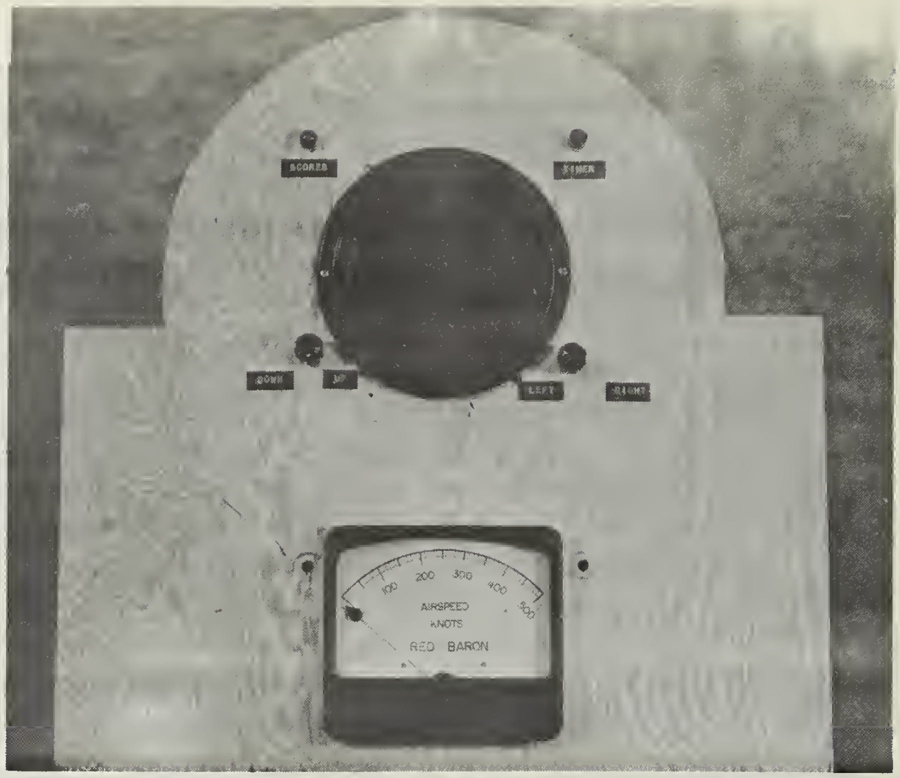

Figure 3. Display Console

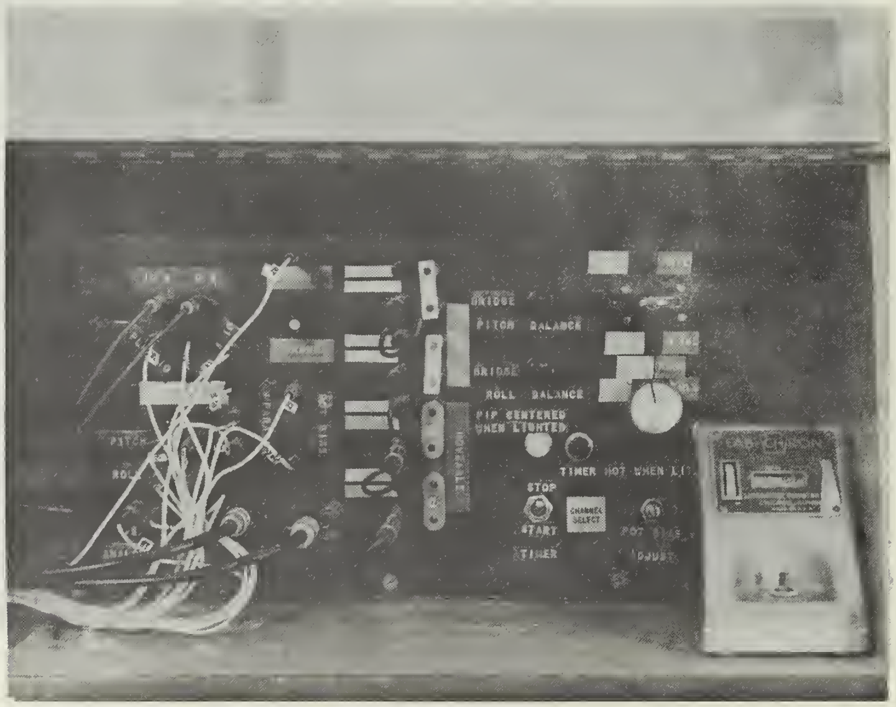

Figure 4. Control and Switching Panel

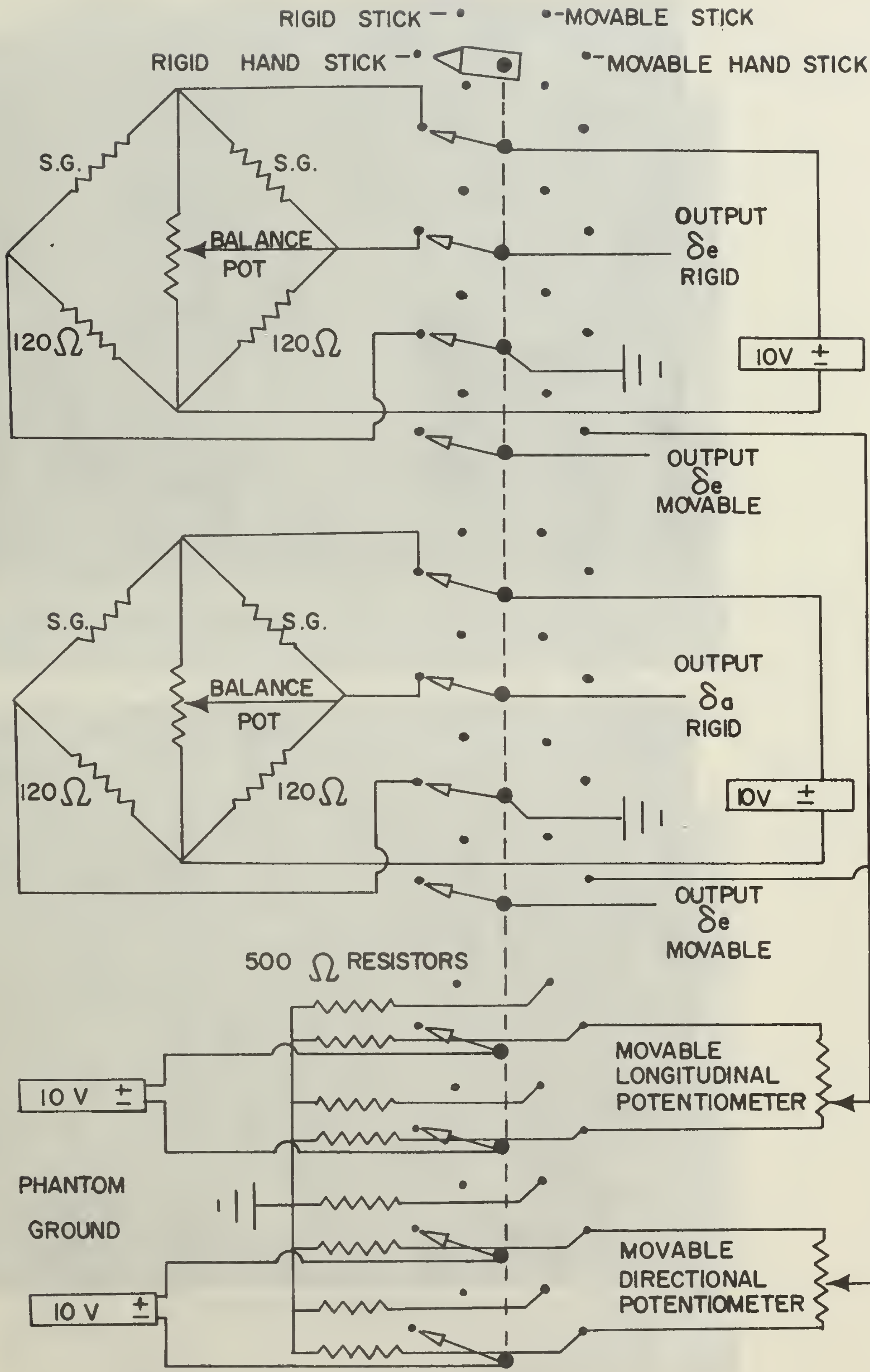

FIGURE 5.
WHEATSTONE BRIDGE AND SWITCHING CIRCUIT

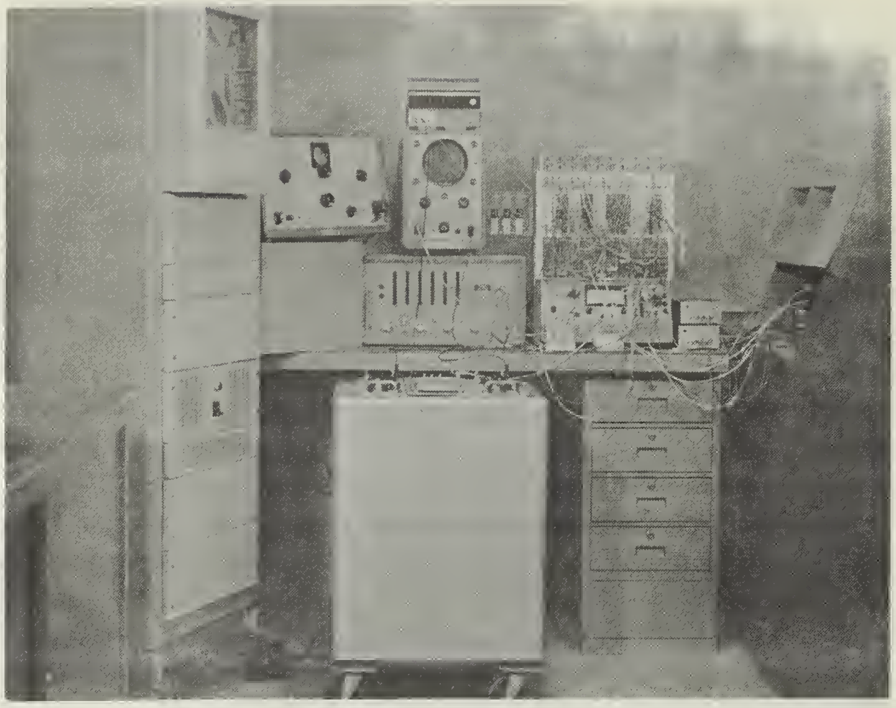

Figure 6. Overall View of Simulator Facility

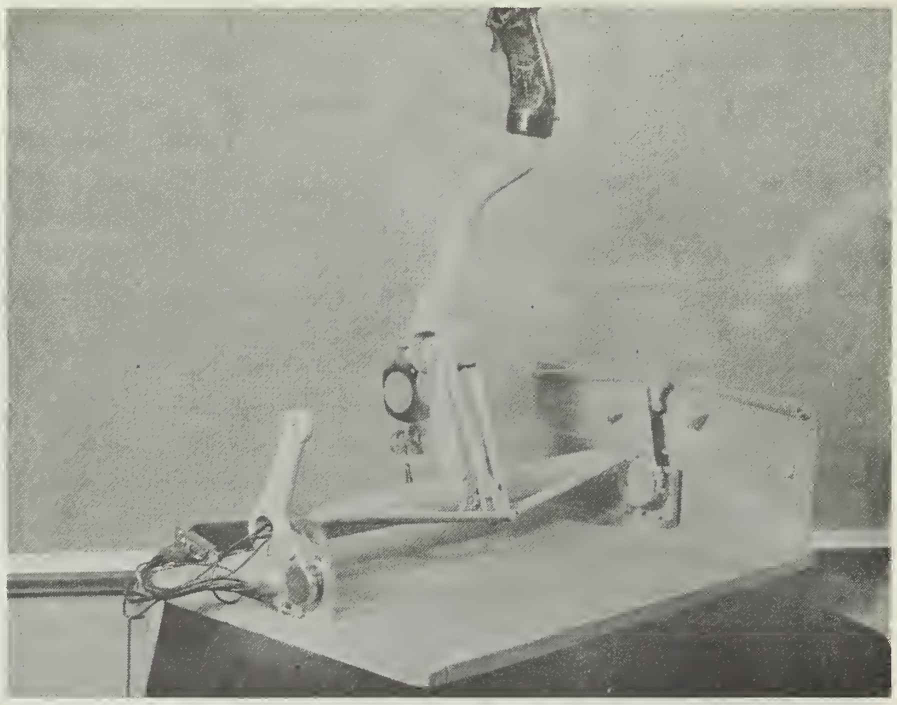

Figure 7. Moveable Deck-mounted Stick

Figure 8. Moveable Hand Control Stick

Figure 9. Rigid Deck-mounted Stick

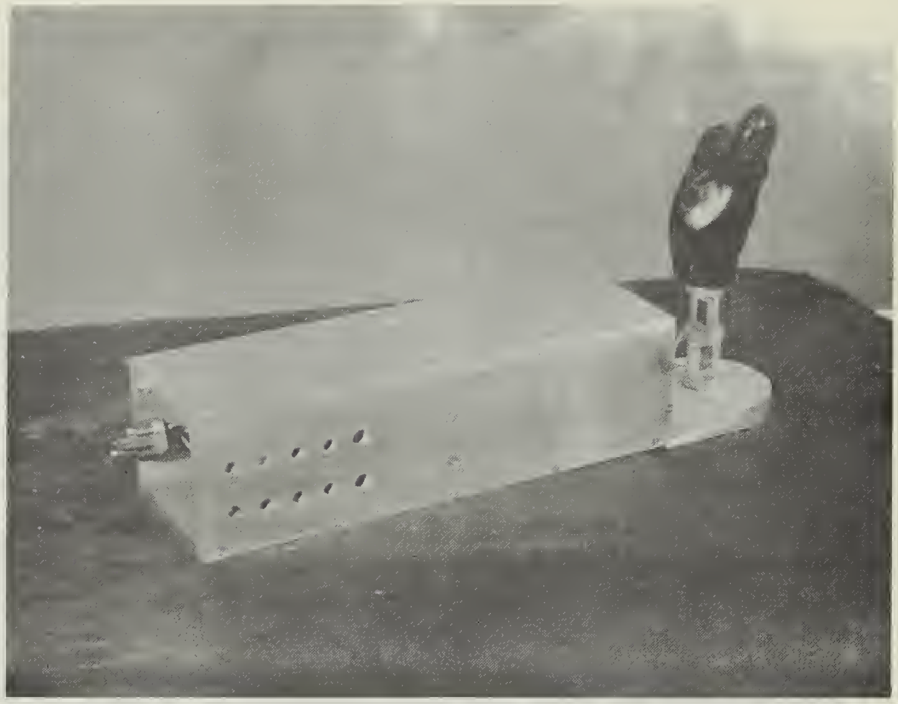
Figure 10 Rigid Hand Control Stick

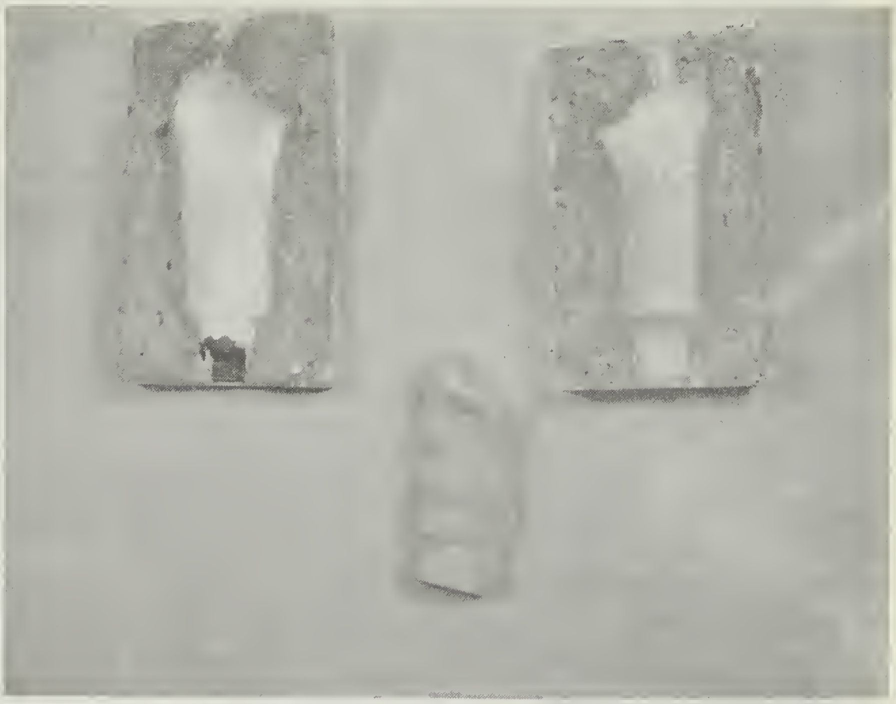
Figure 11. Hand-Grip Model and Molds

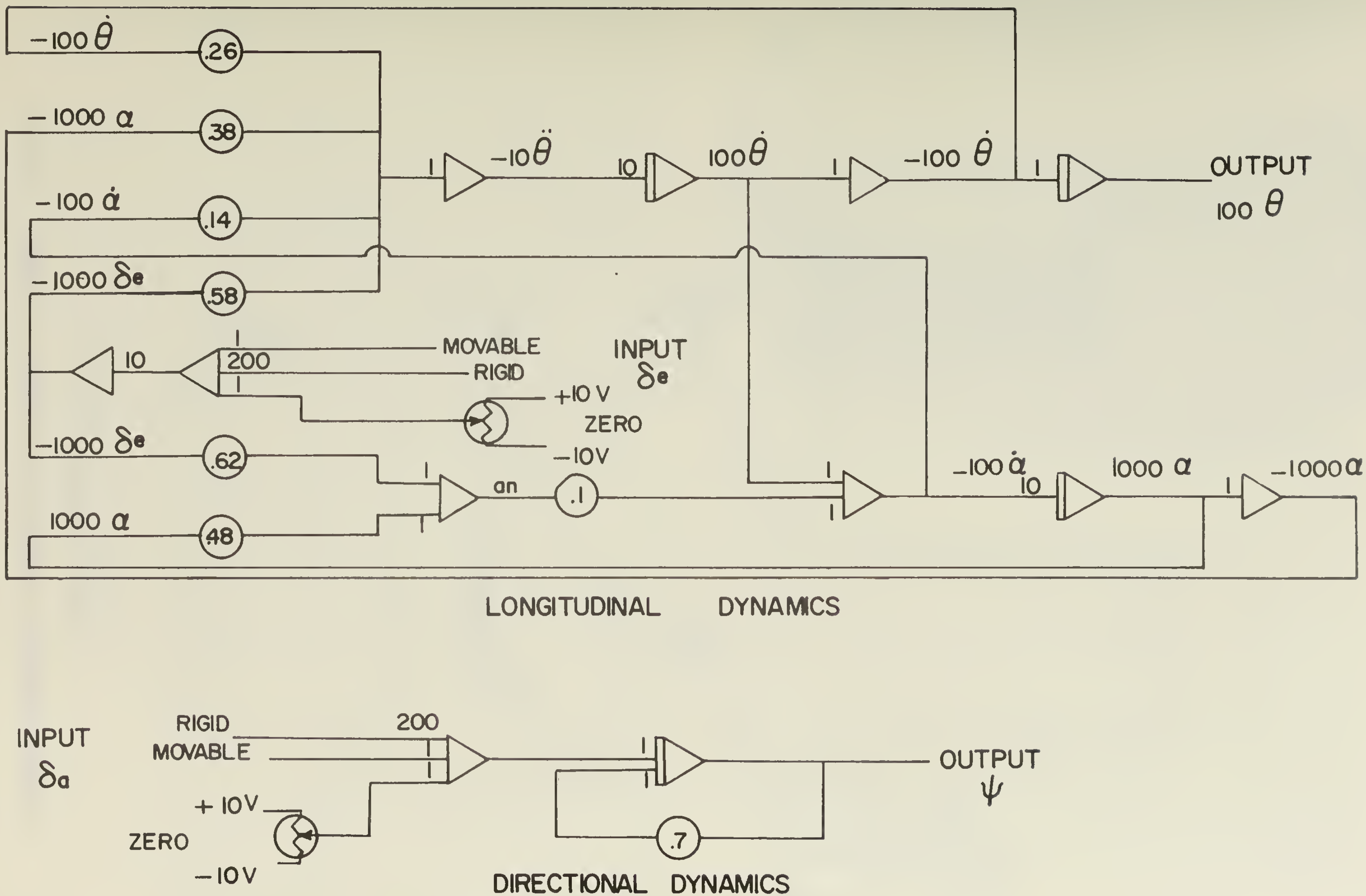

FIGURE 12 . ANALOG COMPUTOR CIRCUIT

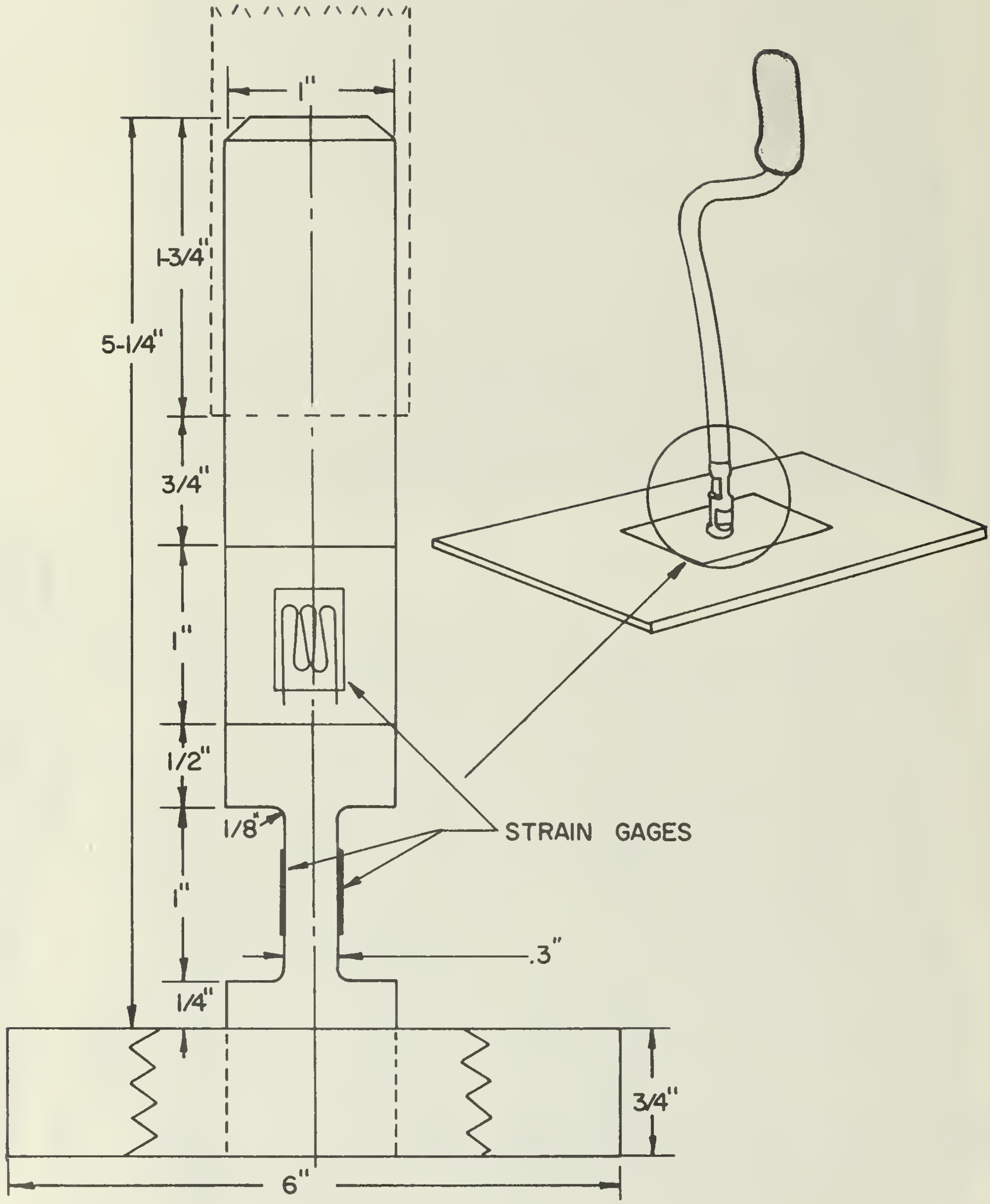

FIGURE 13a

RIGID STICK FLEXURE INSTALLATION

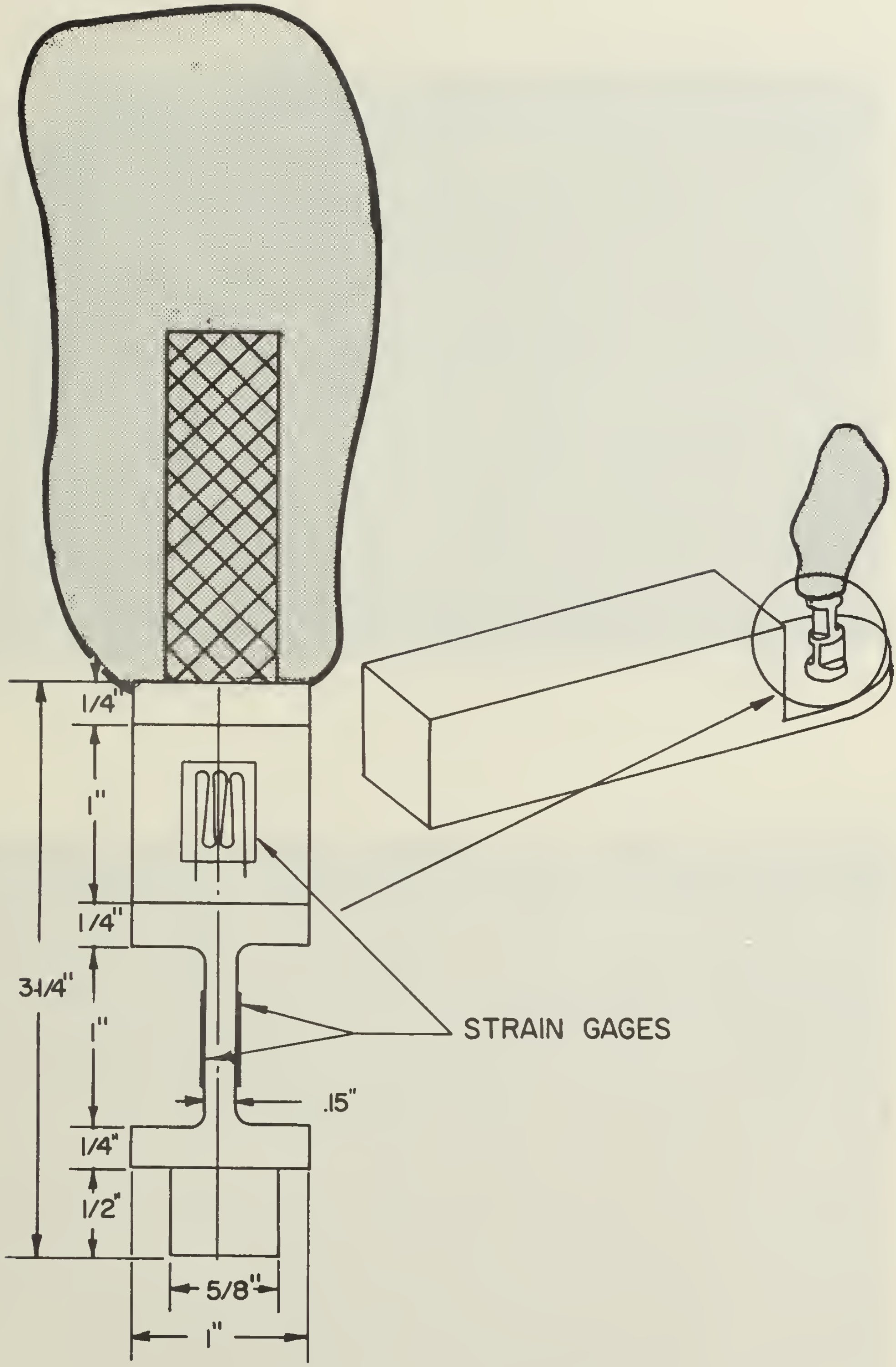

FIGURE 13b.

RIGID HAND STICK FLEXURE INSTALLATION

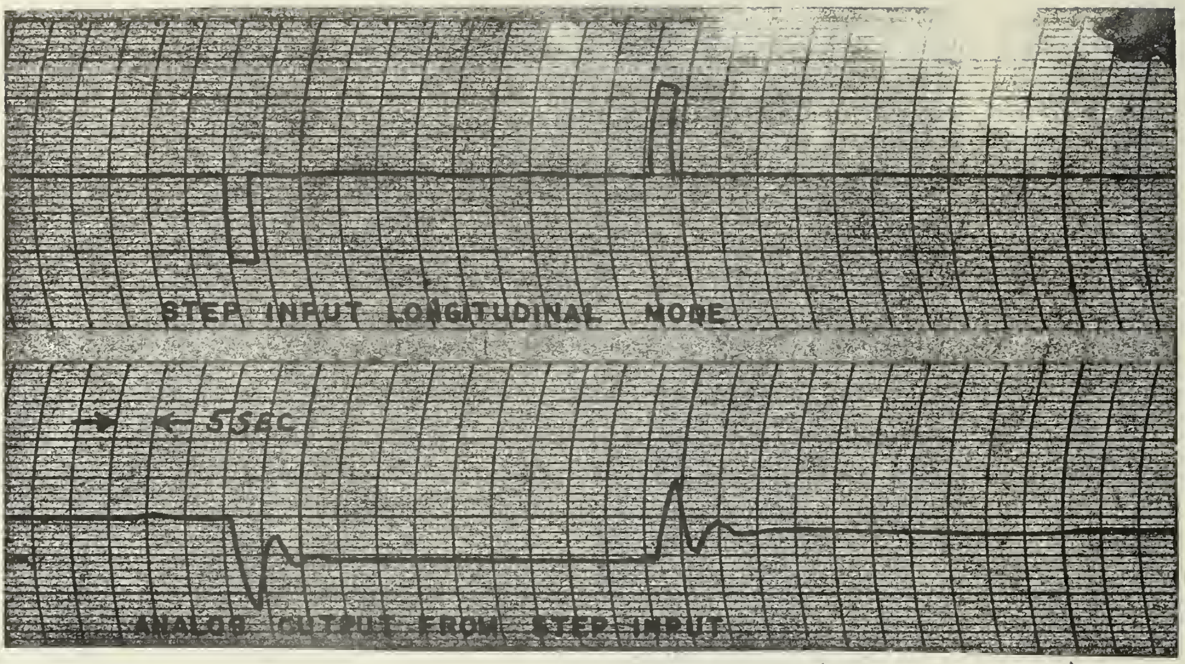

Figure 14. Analog Computer Response (Longitudinal)

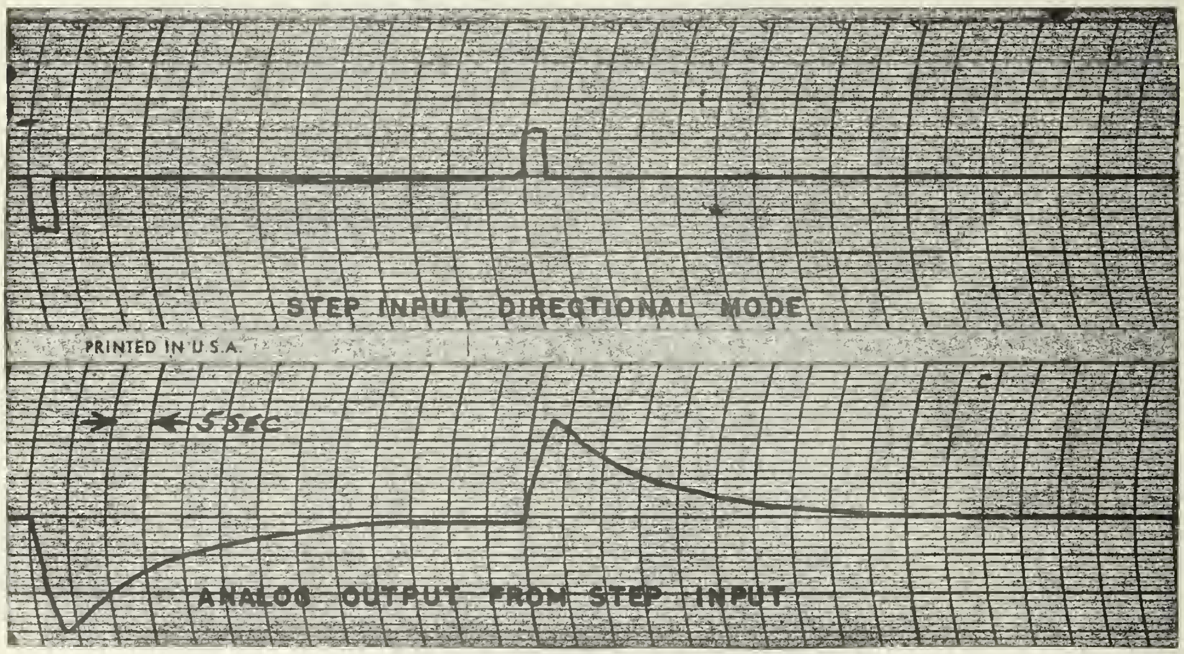

Figure 15. Analog Computer Response (Directional)

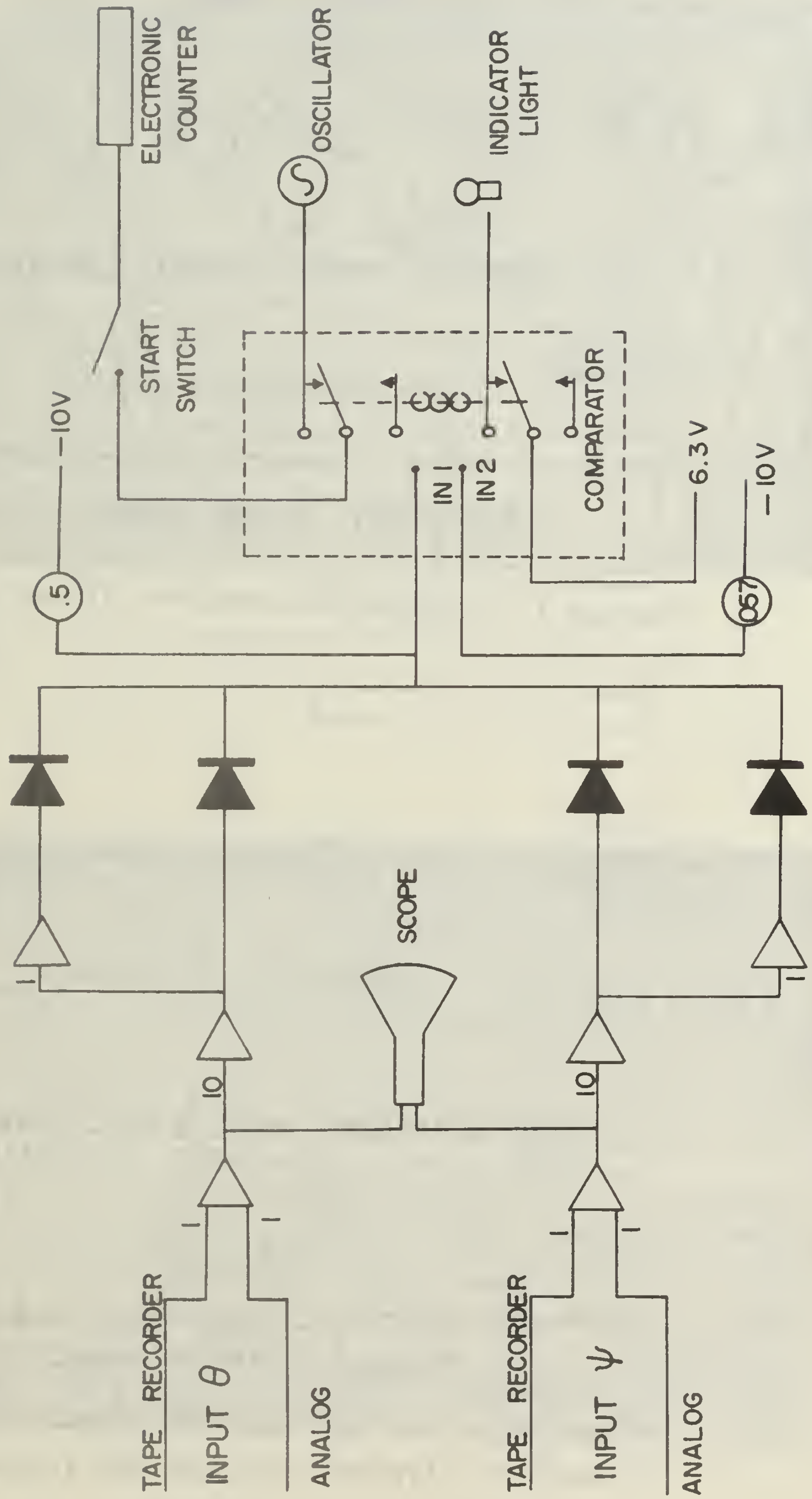

FIGURE 16.
TIMING CIRCUIT

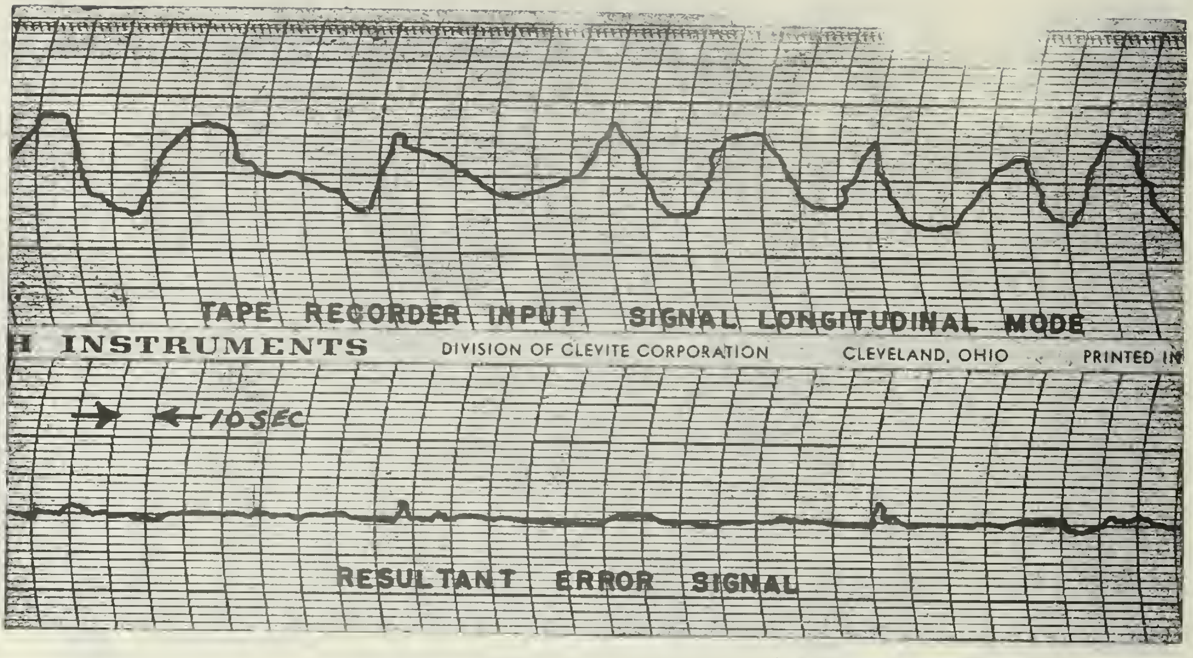

Figure 17. Typical Scoring Run (Longitudinal)

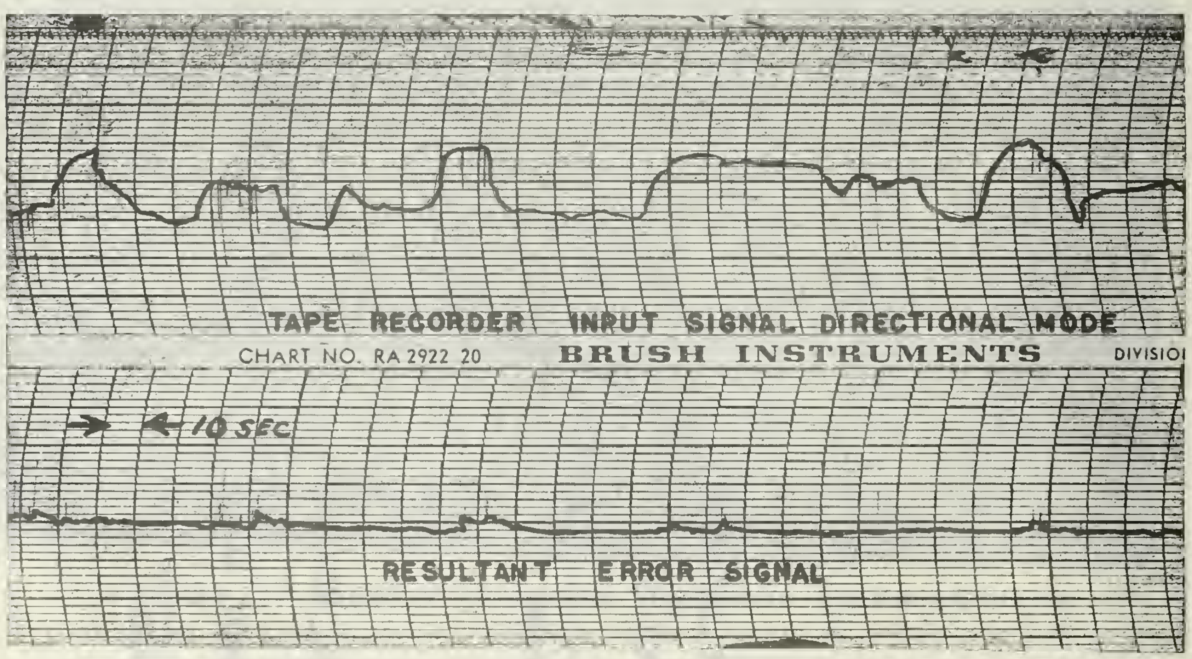

Figure 18. Typical Scoring Run (Directional)

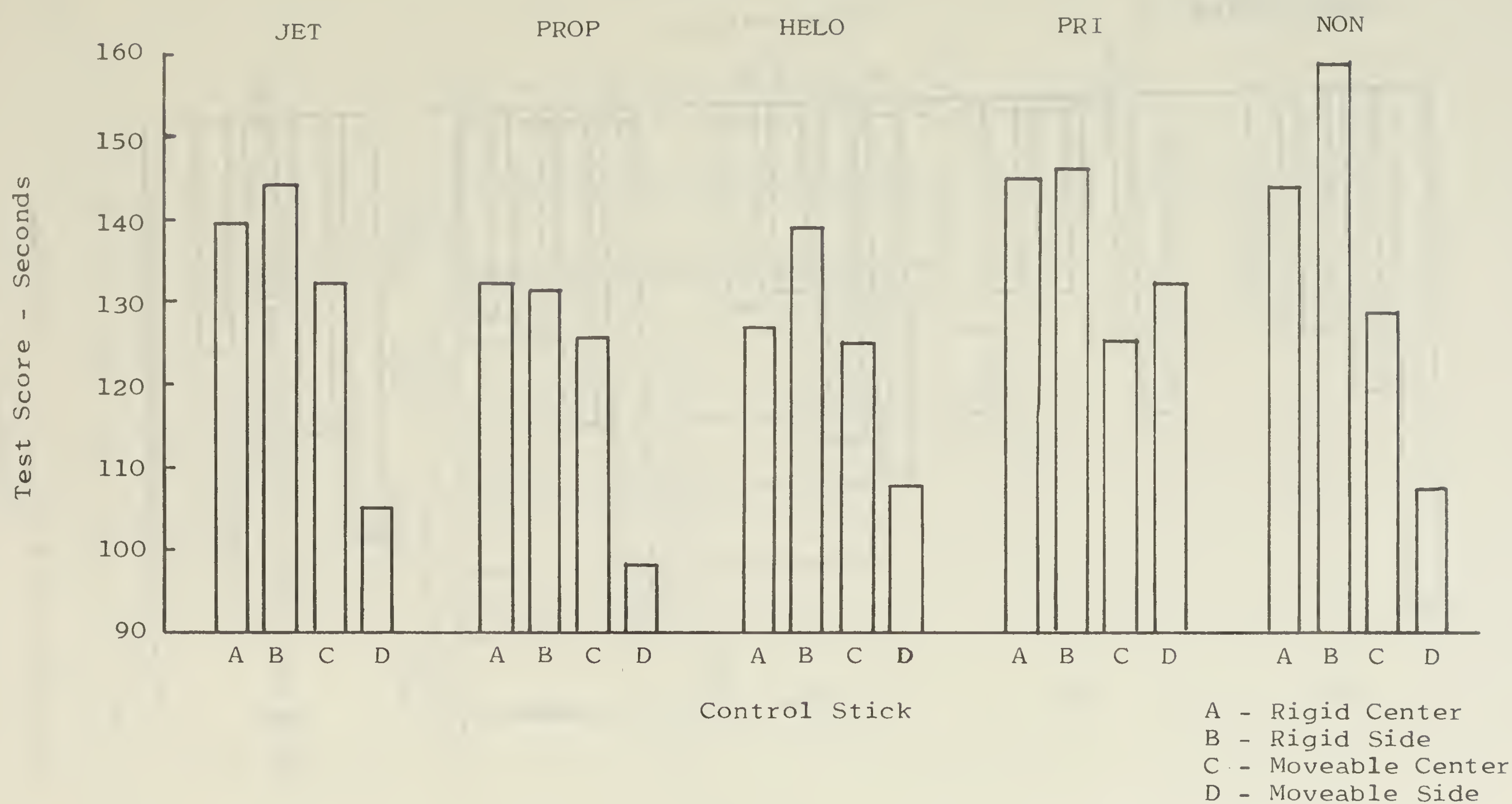

Figure 19. Average Test Score By Each Pilot Classification

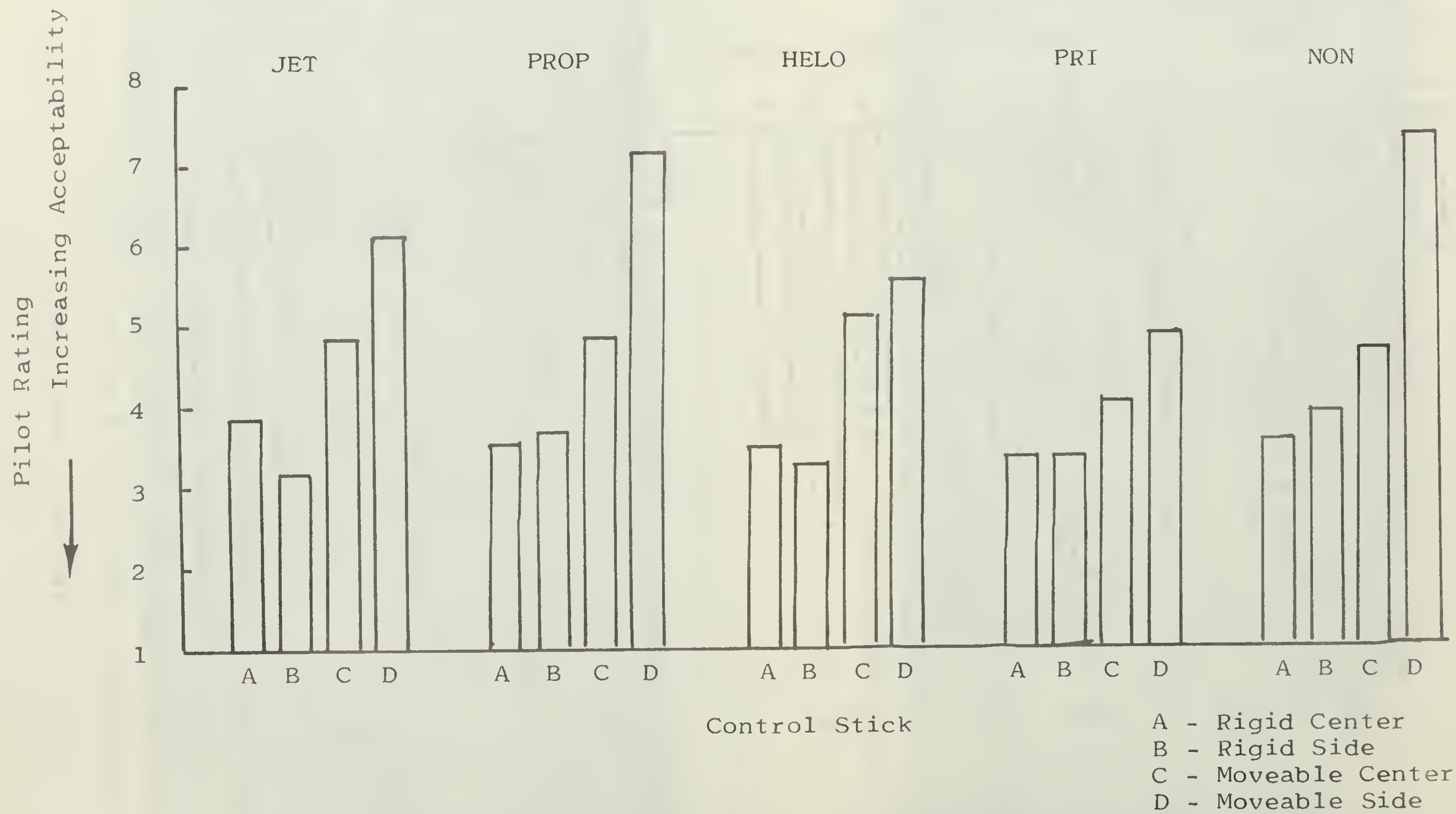

Figure 20. Average Rating By Each Pilot Classification

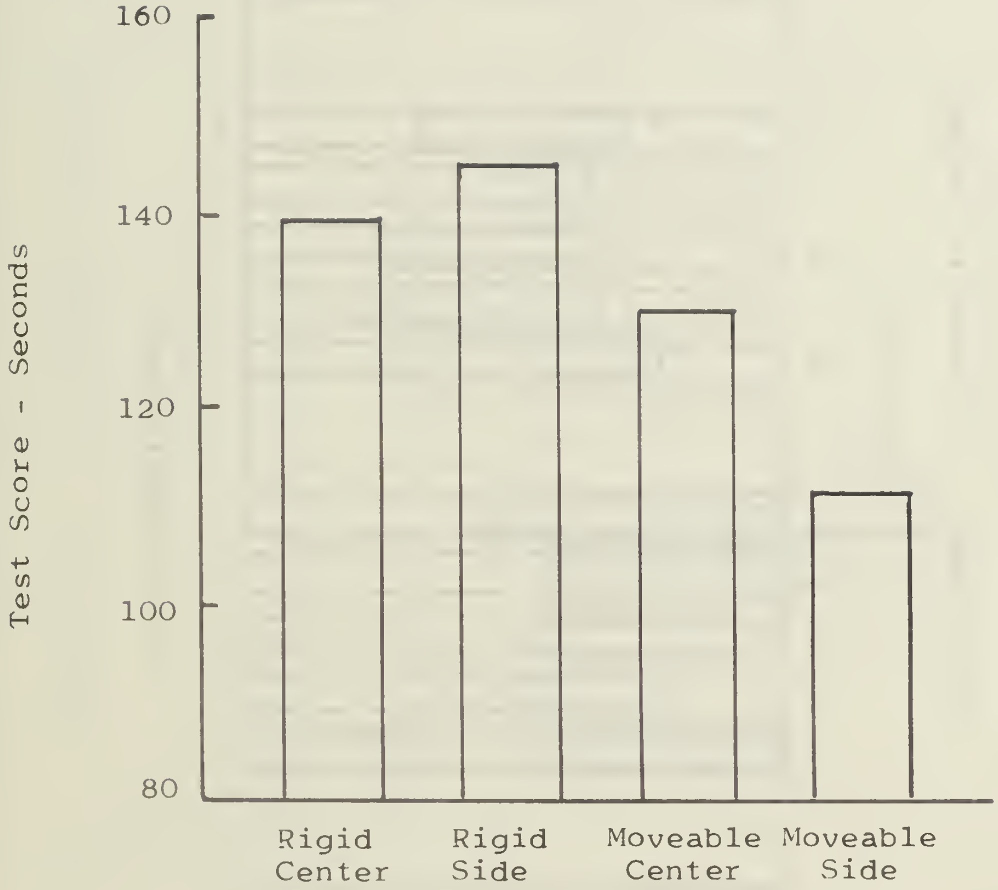

Figure 21. Average Test Score With Each Stick
- All Subjects -

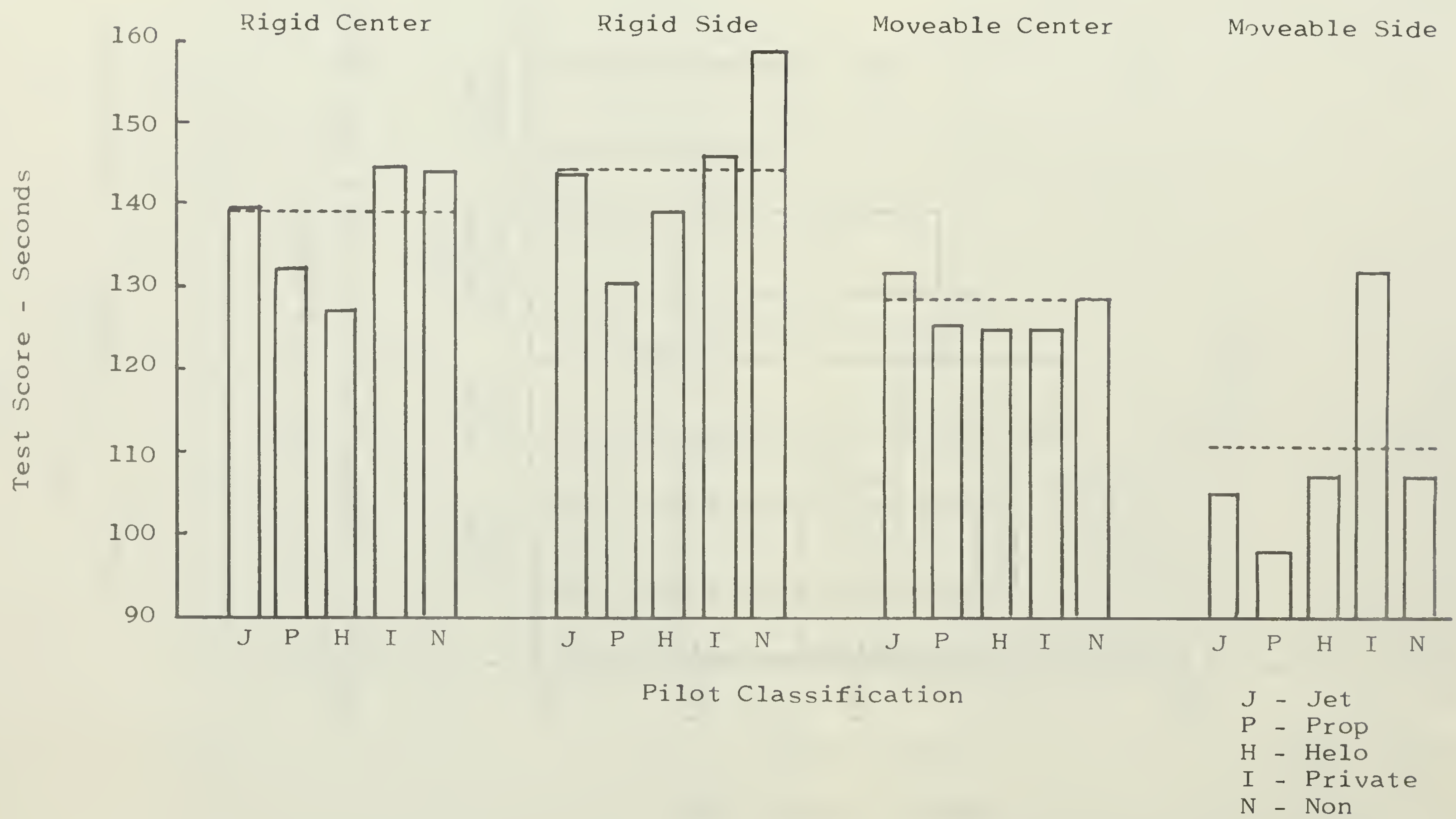

Figure 22. Average Test Score By Pilot Classification For Each Stick

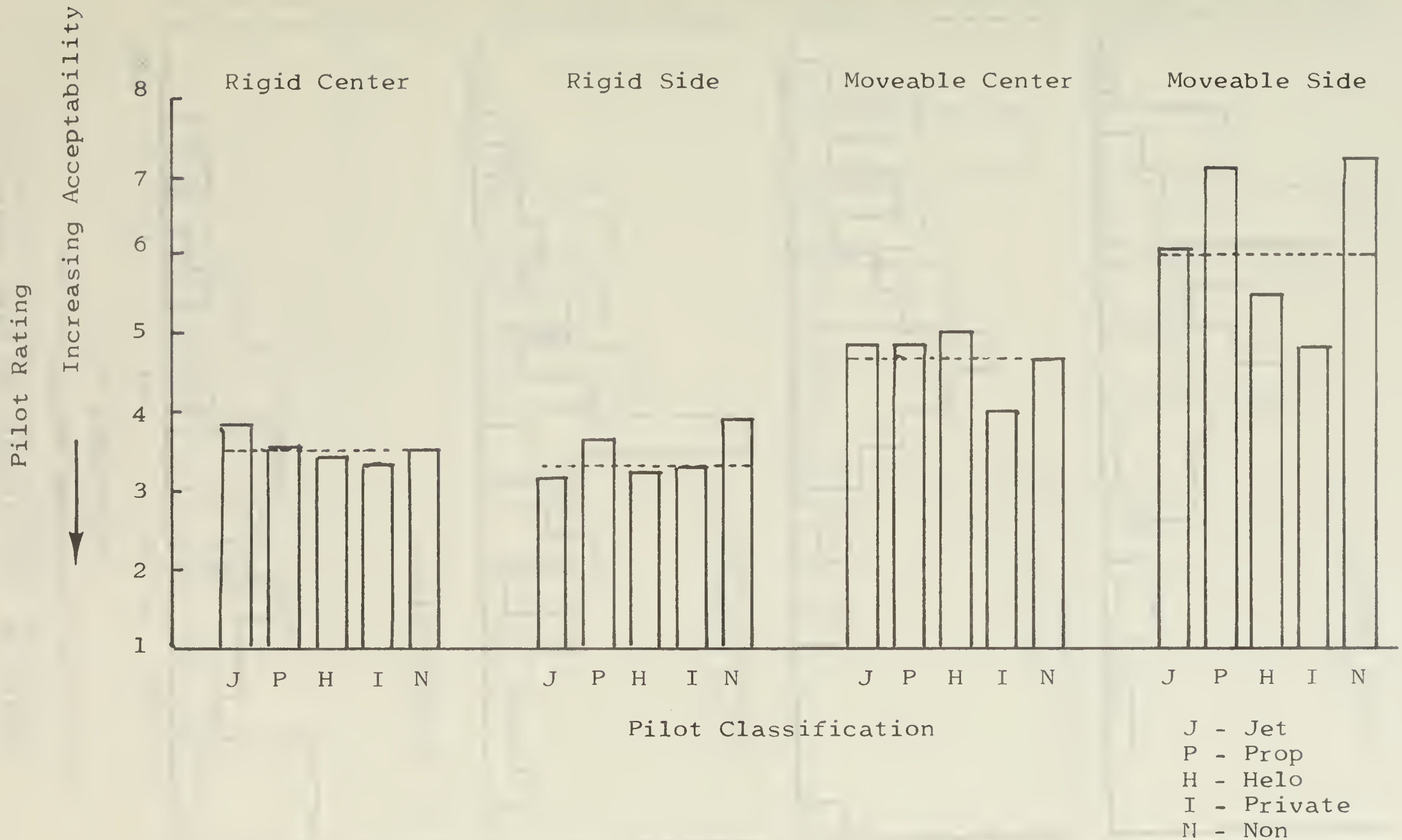

Figure 23. Average Rating By Pilot Classification For Each Control Stick

Figure 24. Distribution of Test Scores
- All Subjects -

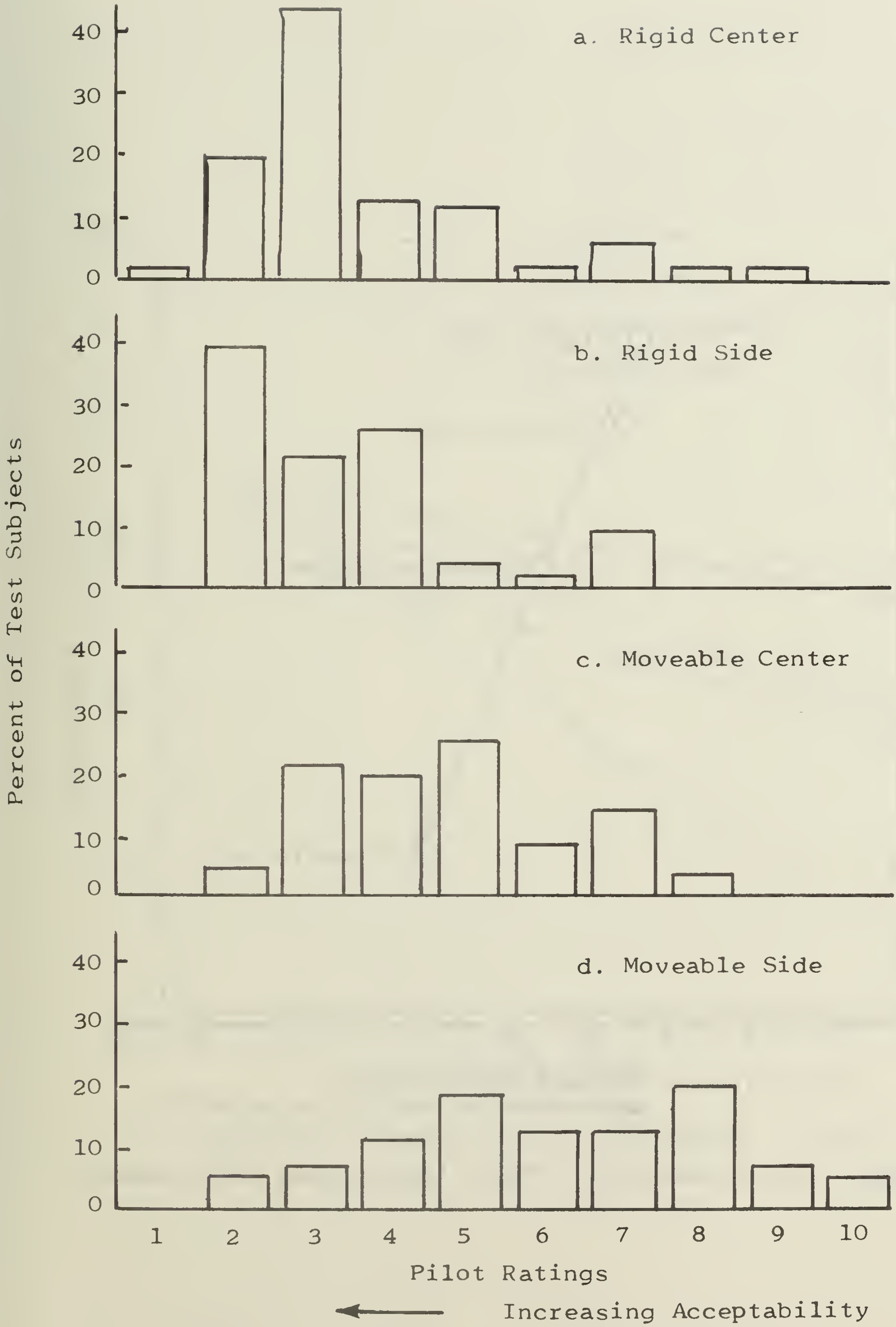

Figure 25. Distribution of Pilot Opinions

- All Subjects -

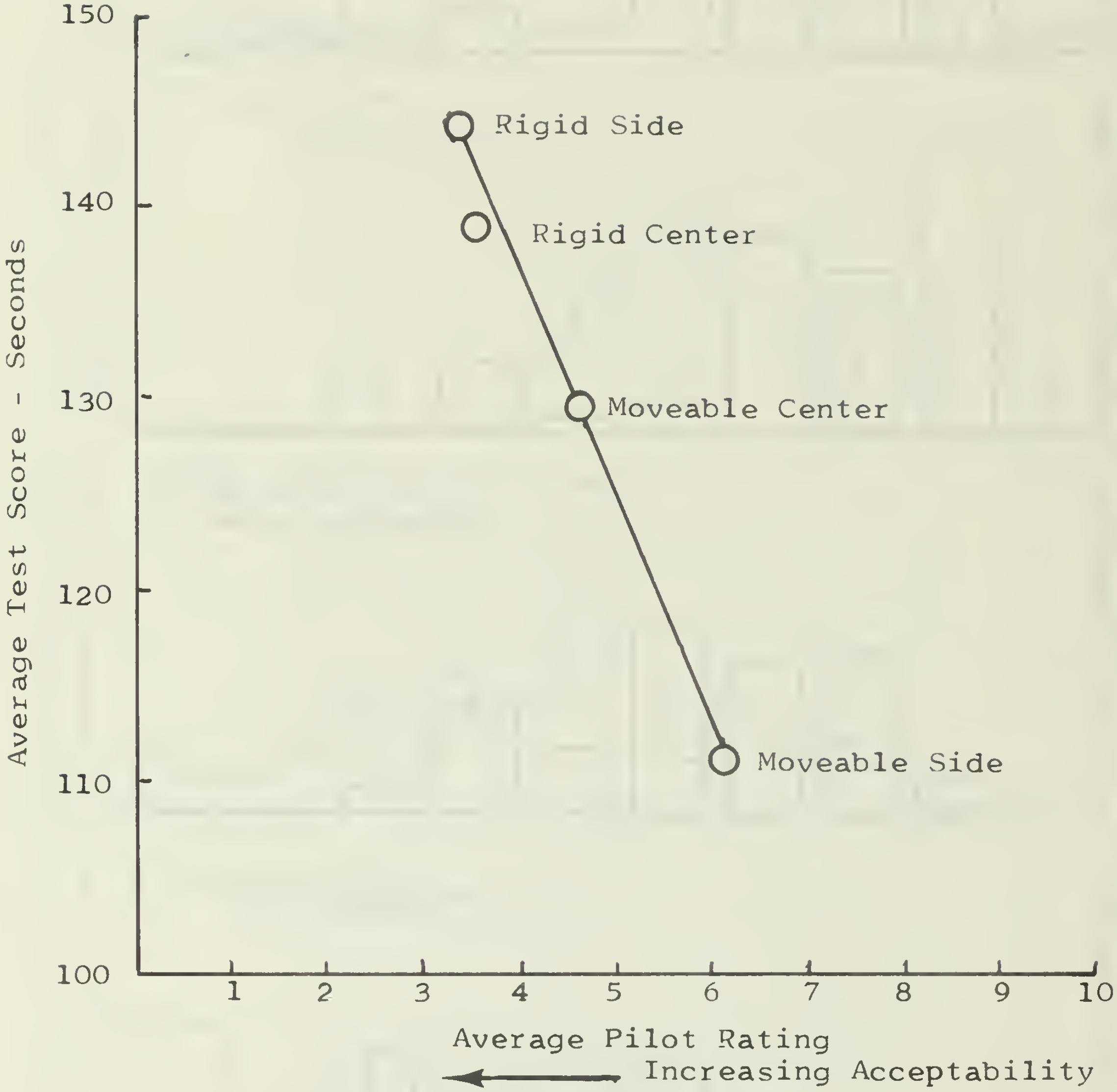

Figure 26. Correlation of Pilot Opinion and Performance

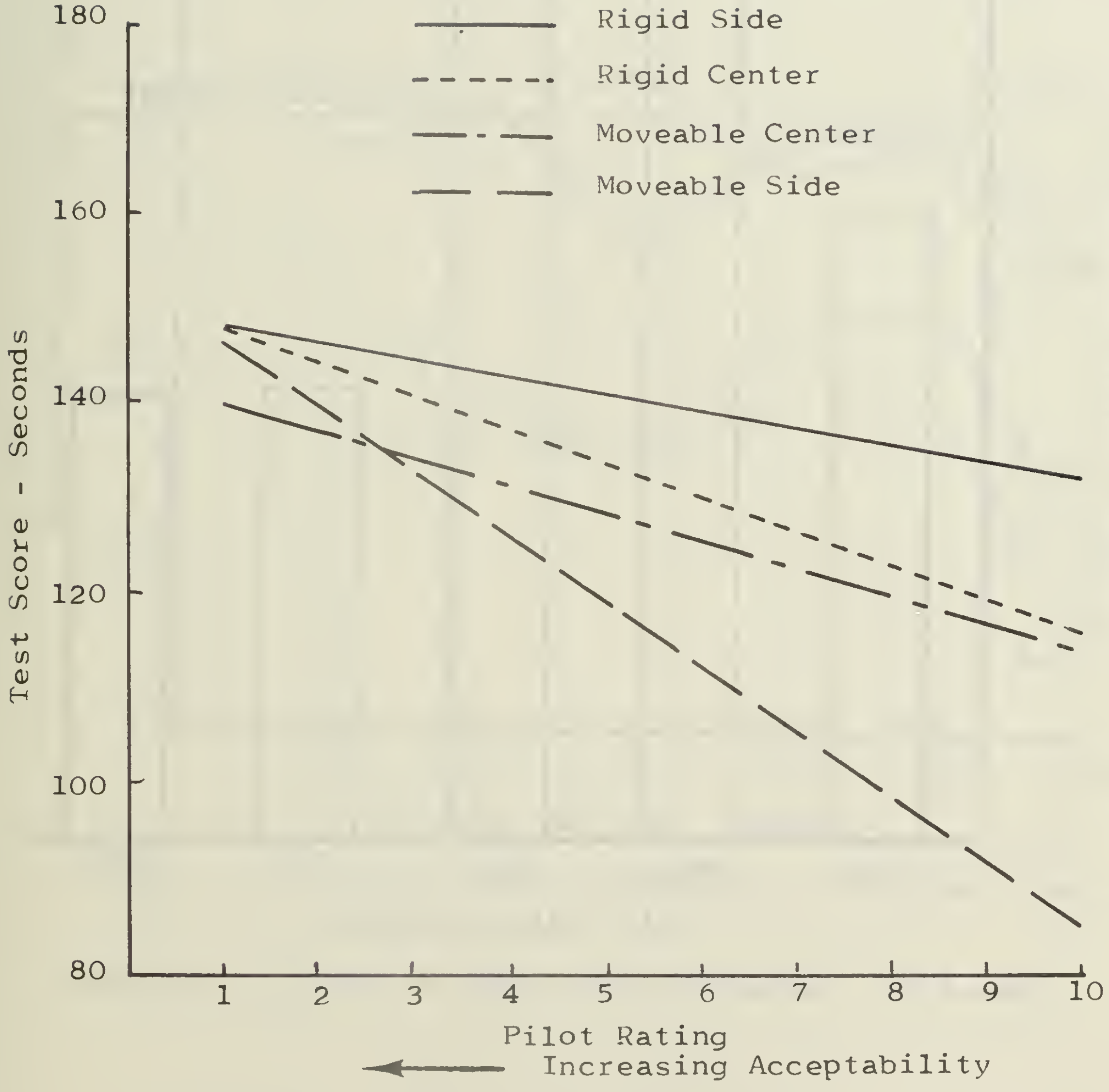

Figure 27. Score-to-Rating Regression Analysis

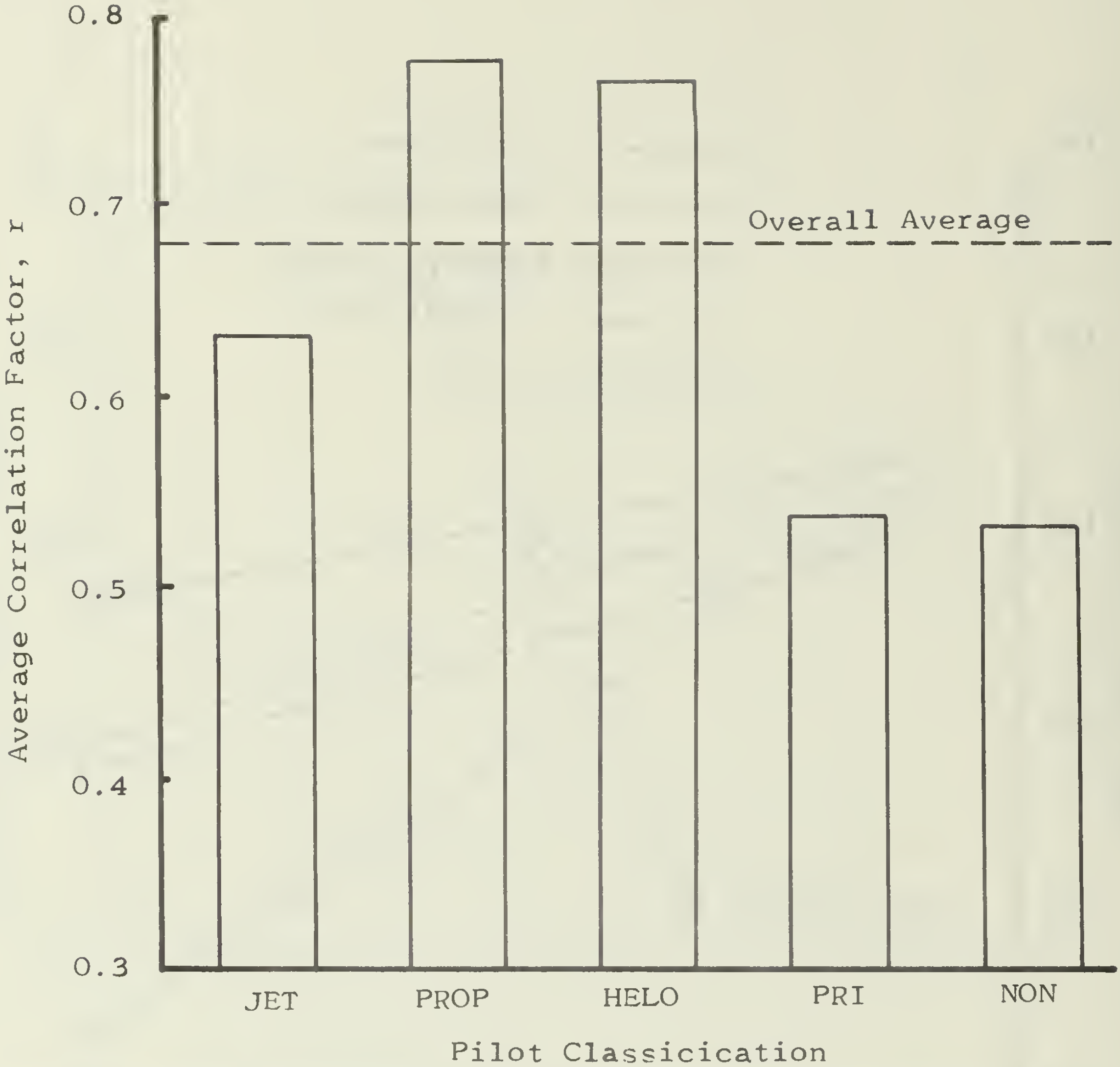

Figure 28. Average Correlat ons of Scores to Opinions

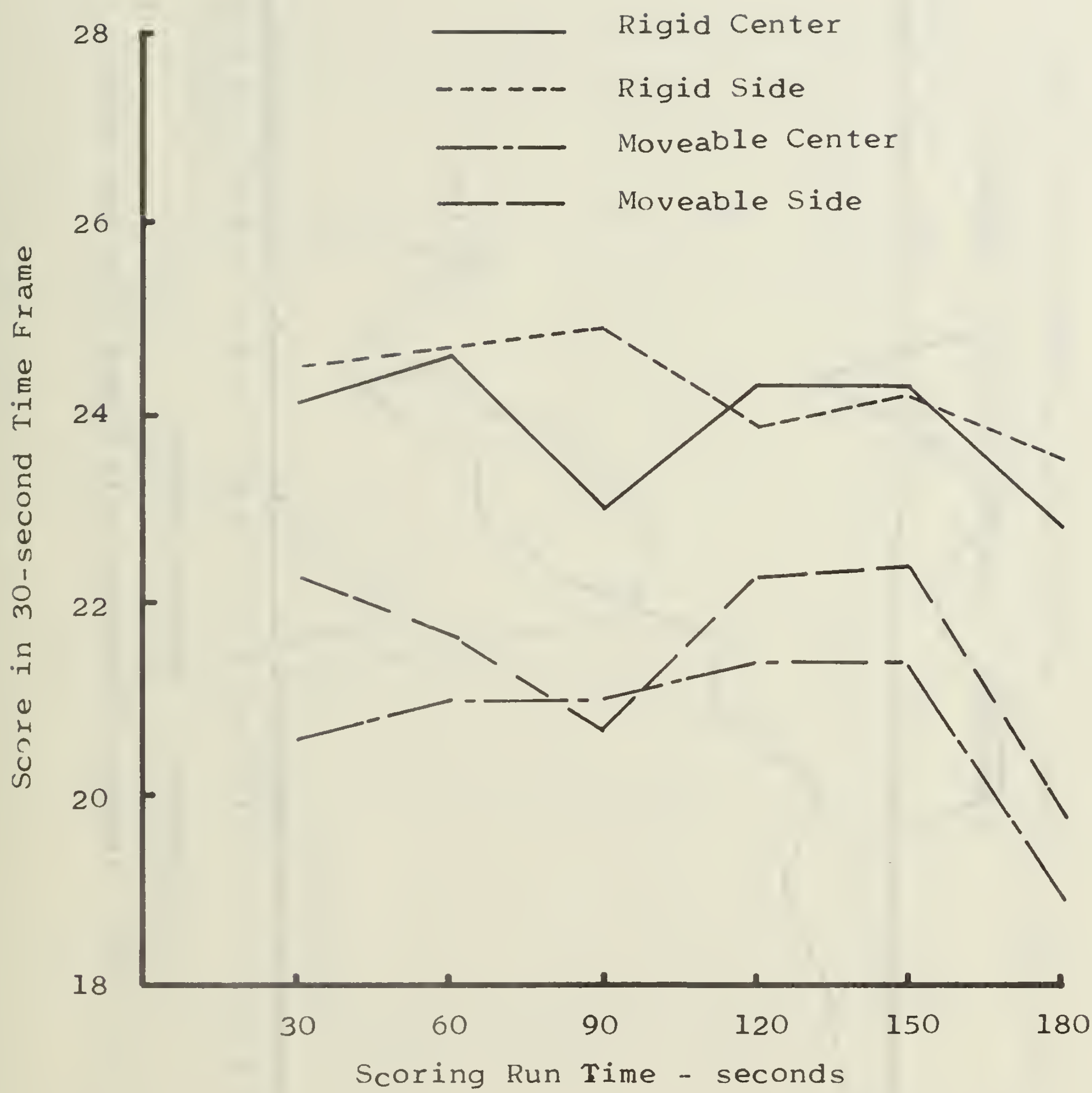

Figure 29. Average Pilot Scoring Pace Throughout Test Run

Figure 30. Pilot Frequency Response with Rigid Side-Arm Stick

Figure 31. Pilot Frequency Response with Moveable Center Stick

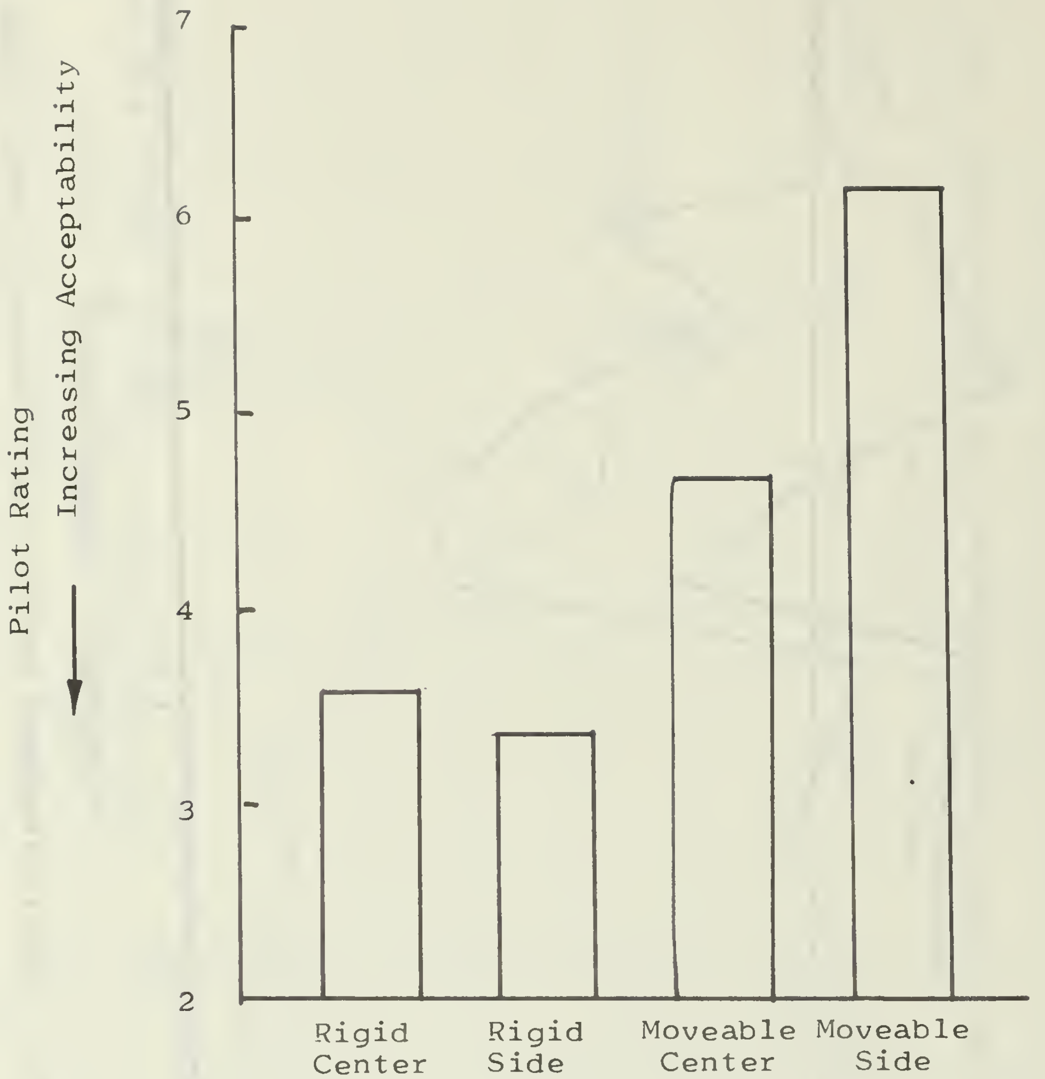

Figure 32. Average Pilot Rating For Each Stick
- All Subjects -

APPENDIX A

LIST OF EQUIPMENT

1. Analog Computer
   Pace TR-10
   Electronic Associates, Inc.

2. Timer (Scorer)
   Universal EPUT and Timer, Model 7350
   Berkeley Division, Beckman Co.

3. Timer
   Lab-Chron
   Laboratories Industries, Inc.

4. Oscilloscope
   Model 120A
   Hewlett-Packard Co.

5. Visual Recorder
   Two-Channel, Model BL-52U
   Brush Electronics Co.

6. Low Frequency Function Generator
   Model 202A
   Hewlett-Packard Co.

7. Power Supply (2)
   Model 3569
   Systems Research Corp.

8. Tape Deck
   One-half inch, Model FR-100A
   Ampex Corp.

APPENDIX B

PILOT FLIGHT EXPERIENCE DATA

SUBJECT	AGE	SEJ	MEJ	SEP	MEP	HELO	PRI	CLASSIFICATION
1	21	- -	- -	- -	- -	- -	- -	NON
2	27	850	- -	300	- -	- -	- -	JET
3	22	- -	- -	- -	- -	- -	- -	NON
4	22	- -	- -	- -	- -	- -	- -	NON
5	35	1500	100	1200	800	15	10	JET/PROP
6	47	- -	- -	700	6300	- -	- -	PROP
7	30	- -	- -	- -	- -	- -	- -	NON
8	30	- -	- -	600	2200	- -	- -	PROP
9	29	- -	- -	- -	2500	- -	- -	PROP
10	30	- -	- -	400	800	- -	- -	PROP
11	28	- -	- -	400	- -	700	- -	HELO
12	32	- -	- -	1000	750	1000	- -	PROP/HELO
13	28	1250	- -	30	80	- -	- -	JET
14	30	11	- -	200	- -	1100	- -	HELO
15	29	- -	- -	- -	2400	- -	- -	PROP
16	28	300	1100	30	8	- -	- -	JET
17	29	- -	- -	100	2300	- -	- -	PROP
18	28	- -	- -	300	- -	2100	- -	HELO
19	29	2500	- -	200	- -	- -	- -	JET
20	28	1400	- -	60	10	- -	10	JET
21	27	1000	- -	300	- -	- -	- -	JET
22	26	- -	- -	140	- -	1800	- -	HELO
23	30	- -	- -	- -	- -	- -	- -	NON
24	26	875	- -	30	- -	- -	- -	JET
25	23	- -	- -	- -	- -	- -	- -	NON
26	28	200	1250	100	50	- -	50	JET
27	28	2700	- -	150	- -	- -	- -	JET
28	27	- -	- -	150	- -	1800	- -	HELO
29	29	700	- -	1300	- -	- -	- -	JET/PROP
30	28	- -	- -	- -	2500	- -	- -	PROP

APPENDIX B
(Continued)

SUBJECT	AGE	SEJ	MEJ	SEP	MEP	HELO	PRI	CLASSIFICATION
31	29	2400	5	300	- -	- -	- -	JET
32	28	- -	- -	200	- -	1700	- -	HELO
33	29	- -	1200	300	- -	- -	- -	JET
34	23	- -	- -	- -	- -	- -	45	PRI
35	24	- -	- -	- -	- -	- -	48	PRI
36	34	1200	2500	400	- -	- -	- -	JET
37	23	- -	- -	- -	- -	- -	- -	NON
38	29	- -	1400	250	- -	- -	- -	JET
39	27	1400	- -	250	- -	- -	- -	JET
40	30	- -	- -	250	- -	1100	- -	HELO
41	22	- -	- -	- -	- -	- -	60	PRI
42	24	- -	- -	- -	- -	- -	160	PRI
43	27	- -	1200	50	- -	10	- -	JET
44	28	- -	- -	250	1400	- -	- -	PROP
45	29	- -	- -	- -	- -	- -	900	PRI
46	28	- -	- -	100	2000	- -	- -	PROP
47	22	- -	- -	- -	- -	- -	60	PRI
48	28	- -	- -	- -	- -	- -	80	PRI
49	31	- -	- -	- -	- -	- -	- -	NON
50	23	- -	- -	- -	- -	- -	- -	NON
51	35	- -	- -	300	4000	- -	50	PROP
52	24	- -	- -	- -	- -	- -	48	PRI
53	31	2000	- -	50	50	- -	- -	JET
54	28	350	200	350	1400	- -	- -	PROP
55	27	- -	- -	100	30	770	- -	HELO
56	22	- -	- -	- -	- -	- -	65	PRI
57	29	- -	- -	250	2350	- -	- -	PROP
58	29	200	- -	1350	- -	- -	- -	PROP
59	26	900	- -	- -	- -	- -	- -	JET
60	27	- -	- -	- -	1400	- -	- -	PROP

APPENDIX B
(Continued)

SUBJECT	AGE	SEJ	MEJ	SEP	MEP	HELO	PRI	CLASSIFICATION
61	28	- -	1400	- -	- -	- -	- -	JET
62	27	- -	- -	250	2100	- -	- -	PROP
63	26	1600	- -	250	- -	- -	- -	JET
64	32	1500	- -	450	- -	- -	80	JET
65	28	150	1150	200	- -	- -	- -	JET
66	27	800	- -	250	- -	- -	- -	JET
67	30	1900	- -	100	- -	- -	- -	JET
68	24	- -	- -	- -	- -	- -	- -	NON
69	30	2200	- -	250	- -	- -	- -	JET
70	28	- -	- -	200	- -	450	- -	HELO
71	22	- -	- -	- -	- -	- -	- -	NON
72	26	1200	- -	250	- -	- -	- -	JET
73	31	- -	- -	200	- -	1200	- -	HELO
74	27	- -	- -	150	- -	820	- -	HELO
75	33	1000	- -	2000	350	- -	- -	JET/PROP
76	30	- -	1500	250	- -	- -	- -	JET
77	36	- -	- -	500	3500	- -	- -	PROP
78	29	- -	- -	200	- -	1600	- -	HELO
79	23	- -	- -	- -	- -	- -	250	PRI
80	28	300	- -	350	1200	- -	- -	PROP
81	29	2600	- -	250	- -	- -	- -	JET
82	30	- -	- -	400	2400	- -	- -	PROP
83	22	- -	- -	- -	- -	- -	- -	NON
84	28	- -	- -	150	- -	1500	- -	HELO
85	29	2500	- -	150	- -	- -	- -	JET
86	28	- -	- -	160	- -	2000	- -	HELO
87	22	- -	- -	- -	- -	- -	- -	NON
88	29	- -	- -	250	- -	1200	- -	HELO
89	23	- -	- -	- -	- -	- -	180	PRI
90	29	- -	1000	250	- -	- -	- -	JET

APPENDIX B
(Continued)

SUBJECT	AGE	SEJ	MEJ	SEP	MEP	HELO	PRI	CLASSIFICATION
91	29	- -	- -	- -	- -	- -	- -	NON
92	30	- -	- -	250	2700	- -	- -	PROP
93	31	- -	- -	300	350	1100	- -	HELO
94	28	1400	- -	250	- -	- -	- -	JET
95	29	250	1400	100	- -	- -	- -	JET
96	22	- -	- -	- -	- -	- -	- -	NON
97	28	- -	- -	250	1400	- -	- -	PROP
98	28	- -	- -	300	- -	2000	- -	HELO
99	28	1500	- -	75	- -	- -	40	JET
100	27	- -	- -	- -	- -	- -	- -	NON
101	33	- -	- -	- -	- -	- -	250	PRI
102	26	- -	- -	- -	- -	- -	- -	NON
103	34	- -	- -	- -	- -	- -	240	PRI
104	31	- -	- -	- -	- -	- -	110	PRI
105	29	- -	- -	300	1600	- -	- -	PROP

SEJ - Single-Engine Jet Hours

MEJ - Multi-Engine Jet Hours

SEP - Single-Engine Prop Hours

MEP - Multi-Engine Prop Hours

HELO - Helicopter Hours

PRI - Private Pilot Hours

APPENDIX C

PILOT SCORING AND RATING DATA

SUBJECT	TEST SCORE				PILOT RATING				TESTING
NUMBER	R.C.	R.S.	M.C.	M.S.	R.C.	R.S.	M.C.	M.S.	ORDER
1	159	174	89	82	3	2	5	8	CDAB
2	161	173	106	122	4	3	6	5	CDAB
3	132	156	160	110	9	7	5	8	ABCD
4	152	171	152	114	3	2	3	9	CDAB
5	107	135	146	81	4	4	7	9	ABCD
6	137	82	138	80	3	6	3	8	ABCD
7	152	171	126	89	4	7	3	10	CDAB
8	130	125	148	90	4	4	5	8	ABCD
9	152	130	145	105	5	3	3	7	ABCD
10	142	148	131	101	3	2	7	8	ABCD
11	125	131	106	87	3	3	5	4	CDAB
12	120	116	120	97	3	4	6	7	ABCD
13	139	132	137	132	7	4	5	4	CDAB
14	125	170	118	102	3	3	5	7	ABCD
15	158	162	138	93	2	4	3	6	CDAB
16	154	161	159	83	7	4	3	8	ABCD
17	110	143	134	90	5	3	4	9	CDAB
18	137	140	134	87	3	2	4	5	ABCD
19	124	137	117	91	3	2	4	5	CDAB
20	96	109	131	87	6	3	5	8	ABCD
21	152	152	139	93	2	2	4	7	CDAB
22	93	139	135	128	8	7	8	6	ABCD
23	151	166	148	153	2	2	4	2	CDAB
24	168	175	165	102	3	3	7	9	CDAB
25	124	132	119	80	2	2	5	10	ABCD
26	146	140	159	88	3	4	5	6	CDAB
27	110	109	98	87	3	2	4	5	ABCD
28	122	126	106	89	3	2	7	8	CDAB
29	142	145	120	94	3	2	5	8	ABCD
30	132	142	121	80	4	3	3	10	CDAB

APPENDIX C
(Continued)

PILOT SCORING AND RATING DATA

SUBJECT	TEST SCORE				PILOT RATING				TESTING
NUMBER	R.C.	R.S.	M.C.	M.S.	R.C.	R.S.	M.C.	M.S.	ORDER
31	126	145	118	99	5	2	7	8	ABCD
32	141	144	131	110	3	2	5	6	CDAB
33	131	138	128	118	3	2	7	8	ABCD
34	166	169	125	163	3	2	5	5	CDAB
35	152	163	159	165	4	4	6	6	ABCD
36	162	151	126	127	4	7	3	3	CDAB
37	162	169	161	168	2	2	4	3	ABCD
38	155	142	151	124	3	4	2	7	ABCD
39	140	138	143	129	3	3	4	5	CDAB
40	138	131	142	136	2	2	2	3	ABCD
41	176	176	168	159	2	2	3	5	ABCD
42	148	143	134	134	5	7	2	2	ABCD
43	153	152	104	118	2	2	2	2	CDAB
44	137	142	123	121	3	3	4	5	ABCD
45	140	139	116	130	2	3	5	4	CDAB
46	135	125	88	110	3	4	4	4	CDAB
47	147	143	134	130	2	2	3	5	ABCD
48	139	137	114	112	1	2	6	6	CDAB
49	134	146	100	105	2	4	7	5	ABCD
50	148	154	134	128	3	5	5	6	ABCD
51	139	160	109	124	4	4	8	7	ABCD
52	128	146	130	136	7	4	3	7	ABCD
53	150	160	130	126	5	4	7	3	CDAB
54	108	83	91	107	5	5	6	4	ABCD
55	143	155	133	134	3	3	4	4	CDAB
56	137	142	151	150	2	2	3	5	ABCD
57	133	143	122	120	2	2	3	5	CDAB
58	142	139	115	132	3	3	4	4	ABCD
59	159	170	109	118	4	3	6	6	CDAB
60	132	125	151	101	4	4	6	8	ABCD

APPENDIX C
(Continued)

SUBJECT	TEST SCORE				PILOT RATING				TESTING
NUMBER	R.C.	R.S.	M.C.	M.S.	R.C.	R.S.	M.C.	M.S.	ORDER
61	124	126	107	94	3	2	8	8	ABCD
62	113	146	132	102	4	3	3	9	CDAB
63	164	153	130	128	3	6	2	2	ABCD
64	148	147	130	104	2	4	6	8	CDAB
65	124	133	123	92	2	2	5	9	CDAB
66	141	132	135	133	6	3	5	4	ABCD
67	112	110	99	92	3	2	5	5	CDAB
68	149	151	142	97	2	3	4	6	ABCD
69	124	130	121	103	3	2	4	5	CDAB
70	124	124	109	96	2	3	7	8	CDAB
71	152	161	137	148	3	2	3	2	ABCD
72	157	140	148	122	2	3	3	7	CDAB
73	136	140	136	96	3	3	4	5	ABCD
74	122	136	113	97	2	4	6	7	CDAB
75	156	164	141	98	3	2	4	5	ABCD
76	156	160	139	97	3	3	4	5	ABCD
77	153	169	127	114	3	4	5	8	CDAB
78	96	125	131	122	6	6	8	7	ABCD
79	165	161	155	152	2	2	3	5	ABCD
80	139	142	126	123	3	3	5	6	CDAB
81	125	146	118	101	4	2	7	8	ABCD
82	137	144	121	120	3	3	4	5	CDAB
83	133	150	102	103	2	3	6	5	ABCD
84	130	143	131	91	4	3	3	9	CDAB
85	129	141	131	122	3	3	7	8	CDAB
86	144	145	132	110	3	3	5	6	ABCD
87	148	153	133	126	3	4	5	6	CDAB
88	137	132	141	133	2	2	2	3	ABCD
89	126	145	129	133	6	4	3	7	CDAB
90	142	133	144	127	3	3	4	6	ABCD

APPENDIX C
(Continued)

SUBJECT	TEST SCORE				PILOT RATING				TESTING
NUMBER	R.C.	R.S.	M.C.	M.S.	R.C.	R.S.	M.C.	M.S.	ORDER
91	134	144	102	107	2	4	6	5	CDAB
92	150	172	123	96	4	6	3	8	ABCD
93	141	150	136	138	3	2	4	4	CDAB
94	142	147	130	92	3	2	4	6	ABCD
95	166	176	162	106	3	2	6	8	CDAB
96	138	151	159	112	8	8	5	9	CDAB
97	110	142	138	89	4	3	4	8	CDAB
98	103	142	140	128	8	6	8	7	ABCD
99	127	132	119	104	3	2	5	5	CDAB
100	144	147	122	98	3	2	5	9	CDAB
101	155	150	102	116	2	2	2	3	ABCD
102	122	134	115	97	2	2	6	10	CDAB
103	146	140	139	132	5	8	2	3	ABCD
104	173	175	170	162	2	2	4	6	CDAB
105	139	95	145	96	2	5	3	9	CDAB

A - Rigid Center Stick (R.C.)

B - Rigid Side Stick (R.S.)

C - Moveable Center Stick (M.C.)

D - Moveable Side Stick (M.S.)

APPENDIX D

DISTRIBUTIONS

of

TEST SCORES

and

RATINGS

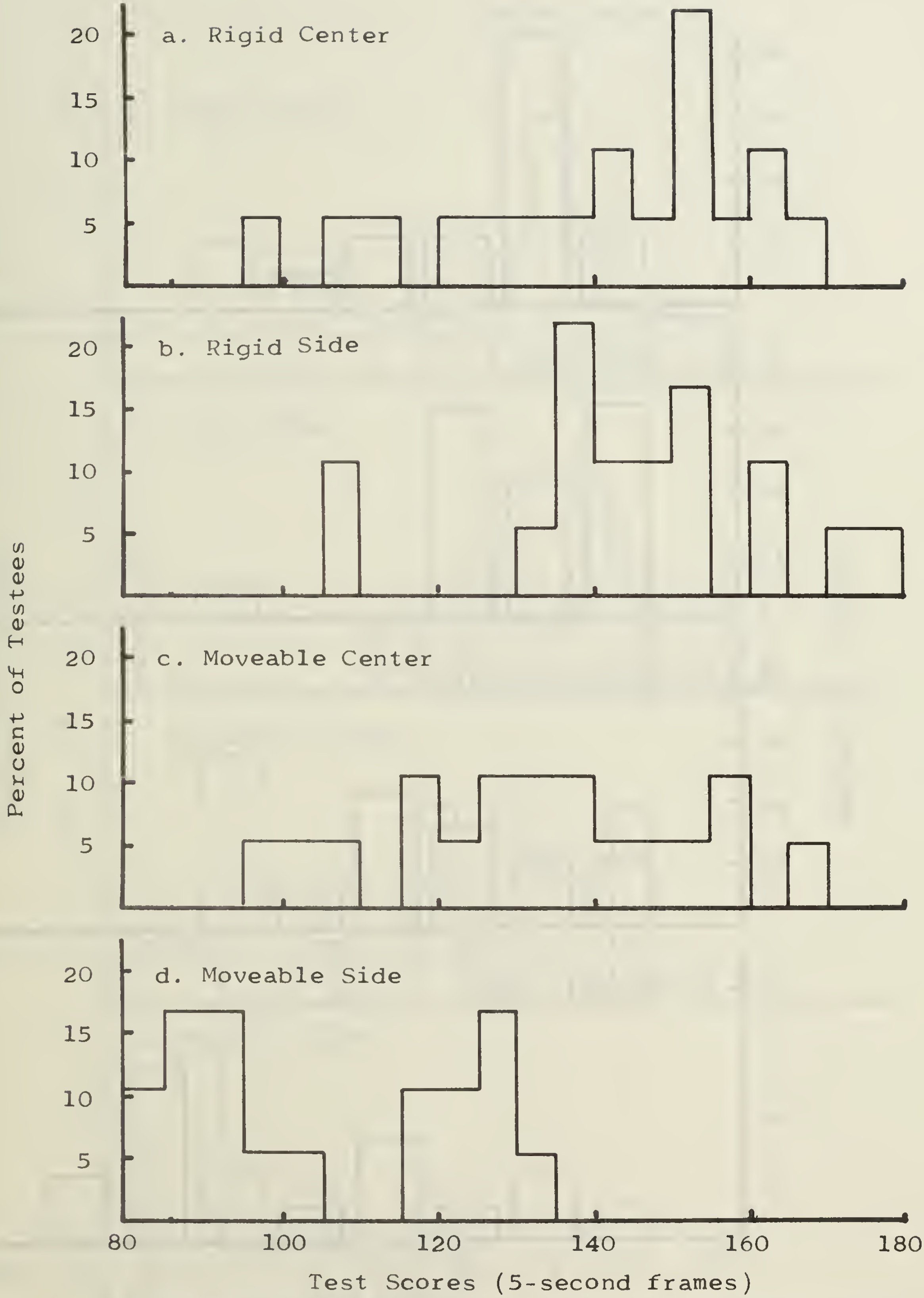

Figure D-1. Distribution of Test Scores - Jet Pilots

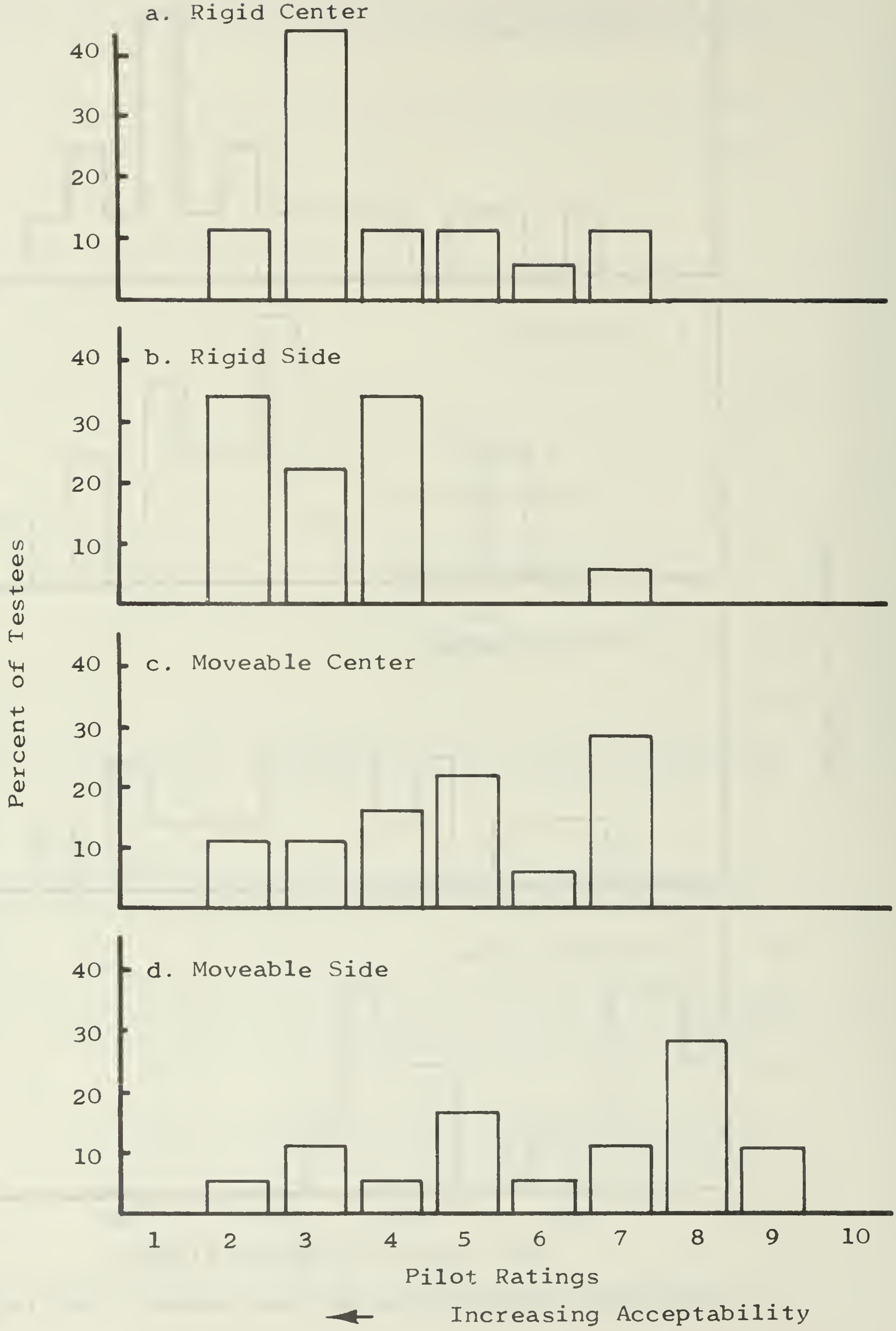

Figure D-2. Distribution of Opinions - Jet Pilots

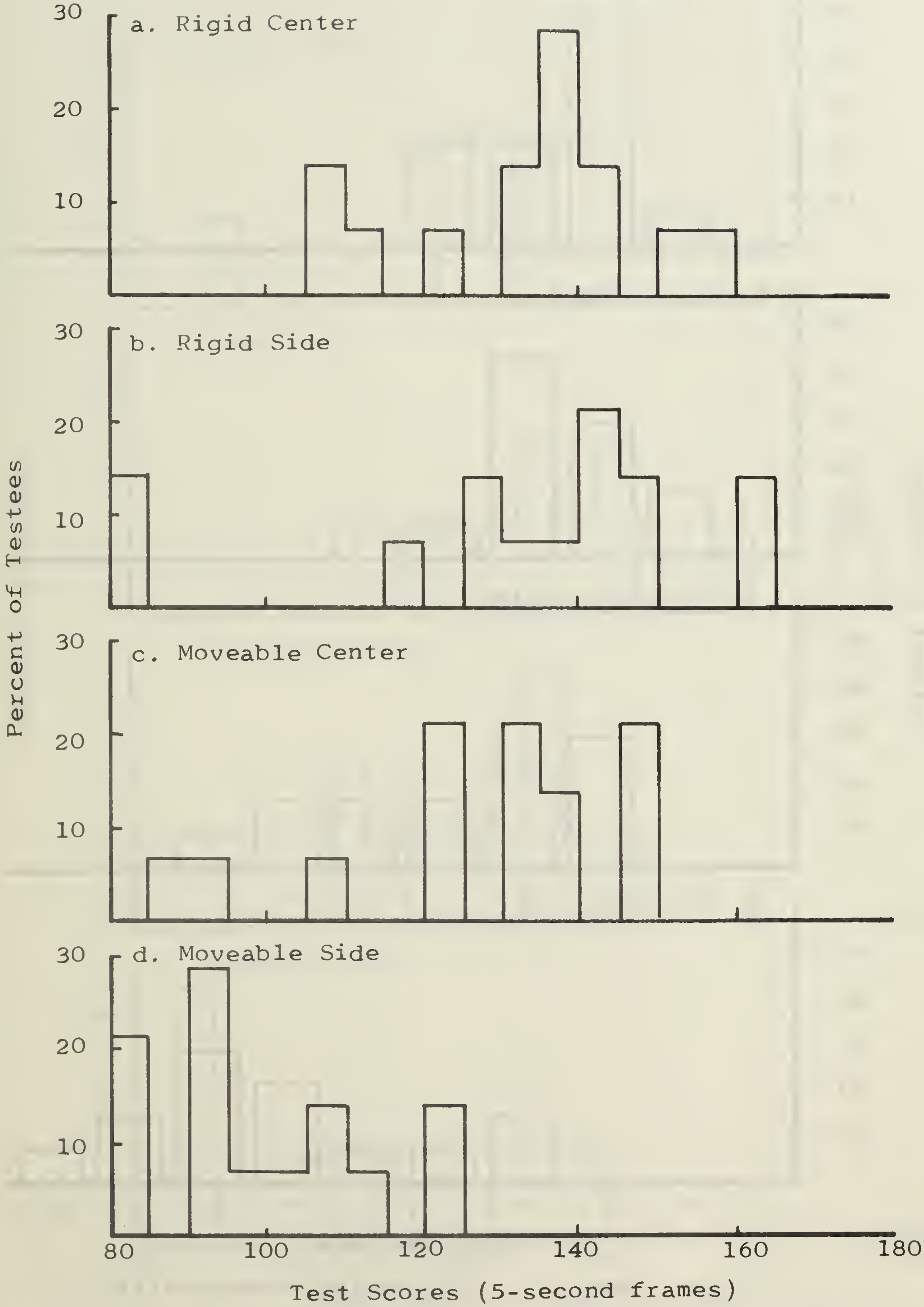

Figure D-3. Distribution of Test Scores - Prop Pilots

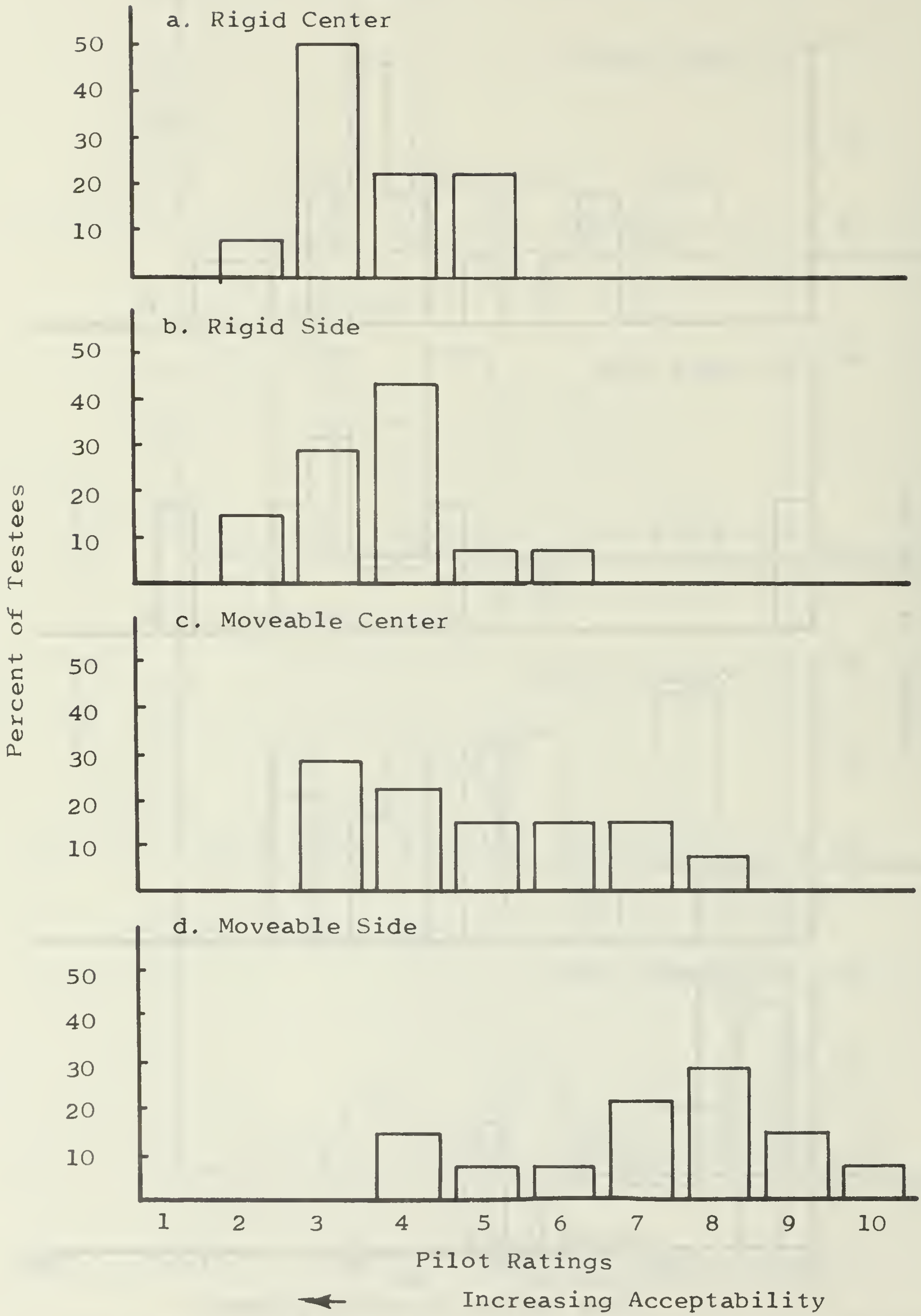

Figure D-4. Distribution of Opinions - Prop Pilots

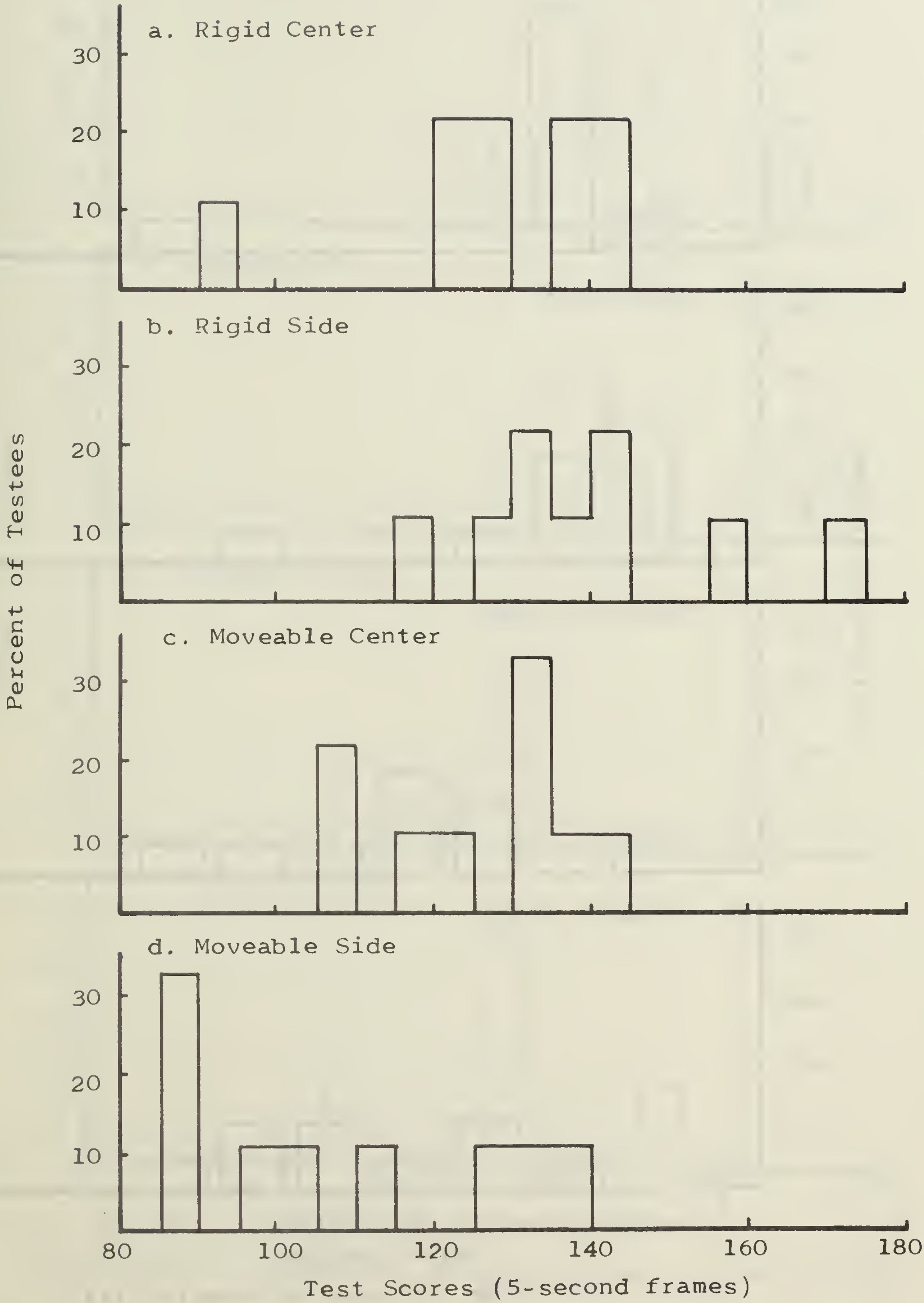

Figure D-5. Distribution of Test Scores - Helo Pilots

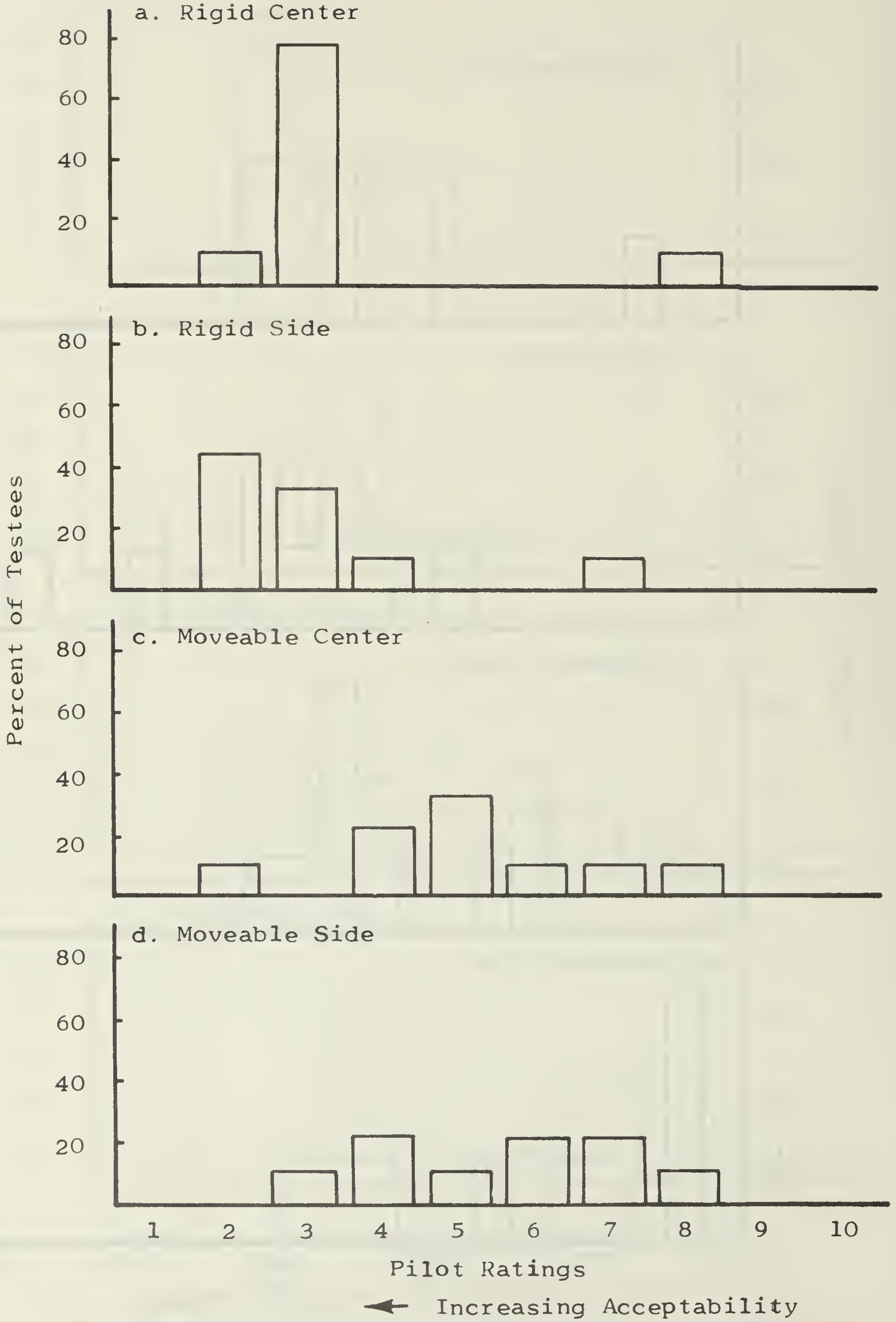

Figure D-6. Distribution of Opinions - Helo Pilots

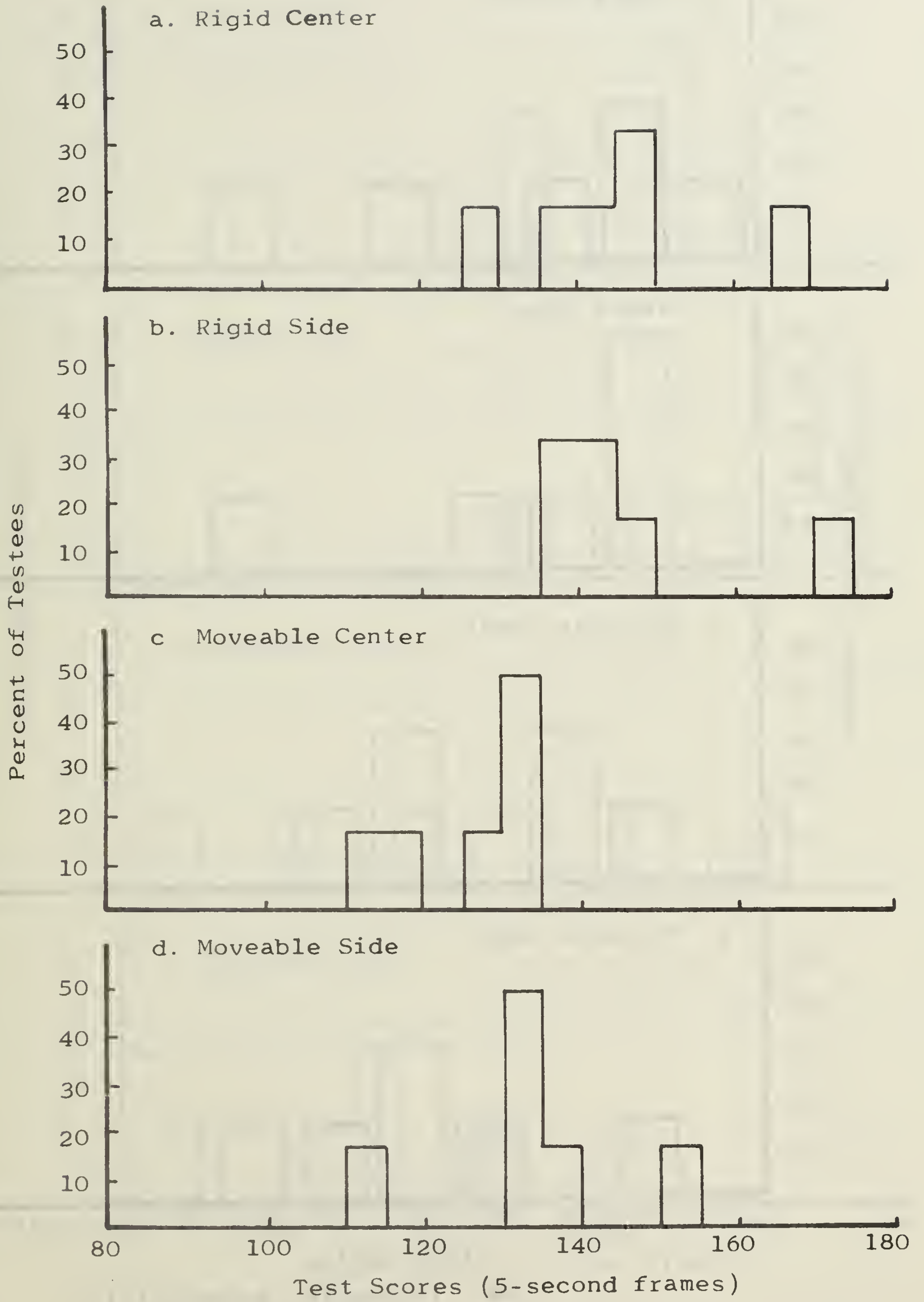

Figure D-7. Distribution of Test Scores - Private Pilots

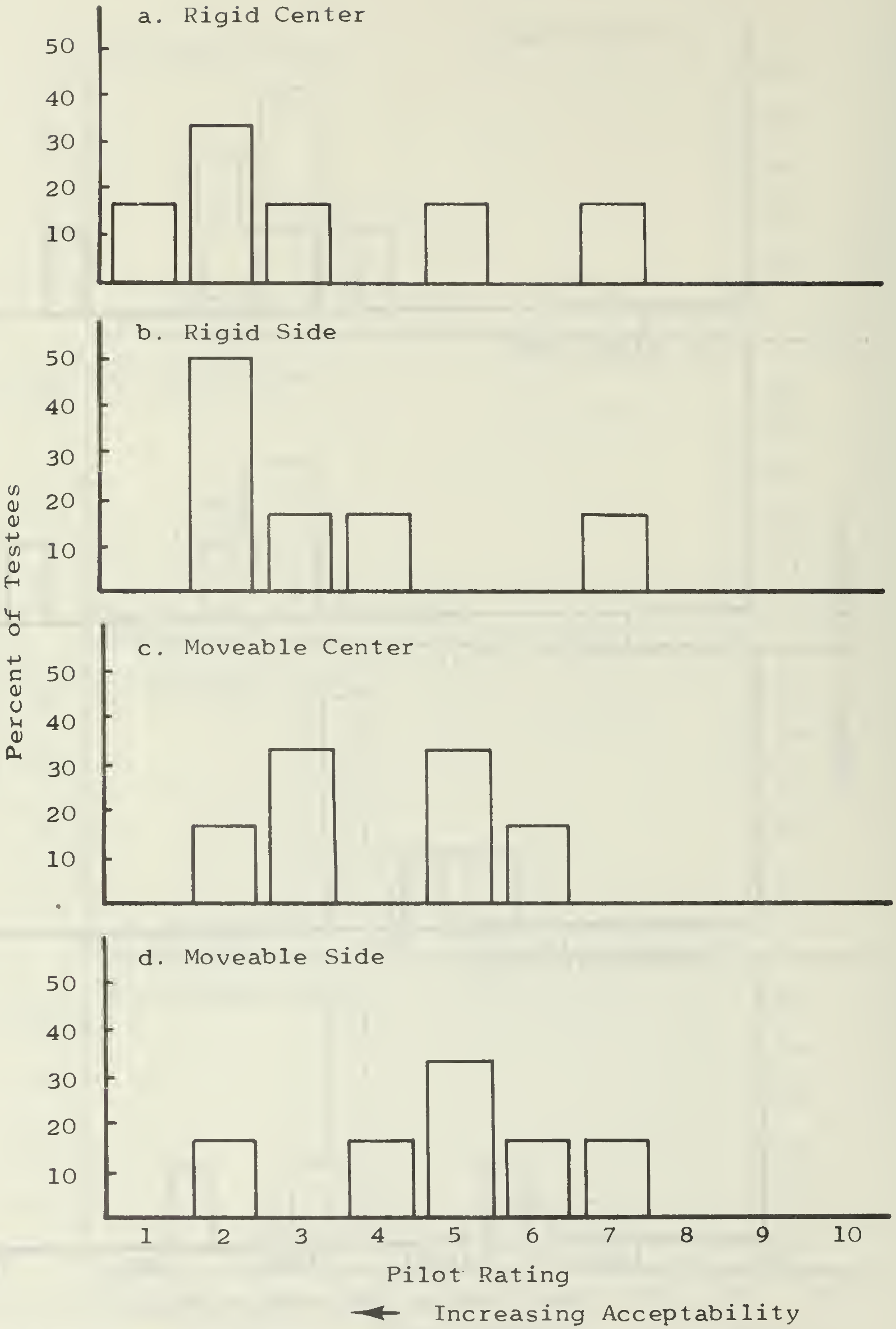

Figure D-8. Distribution of Opinions - Private

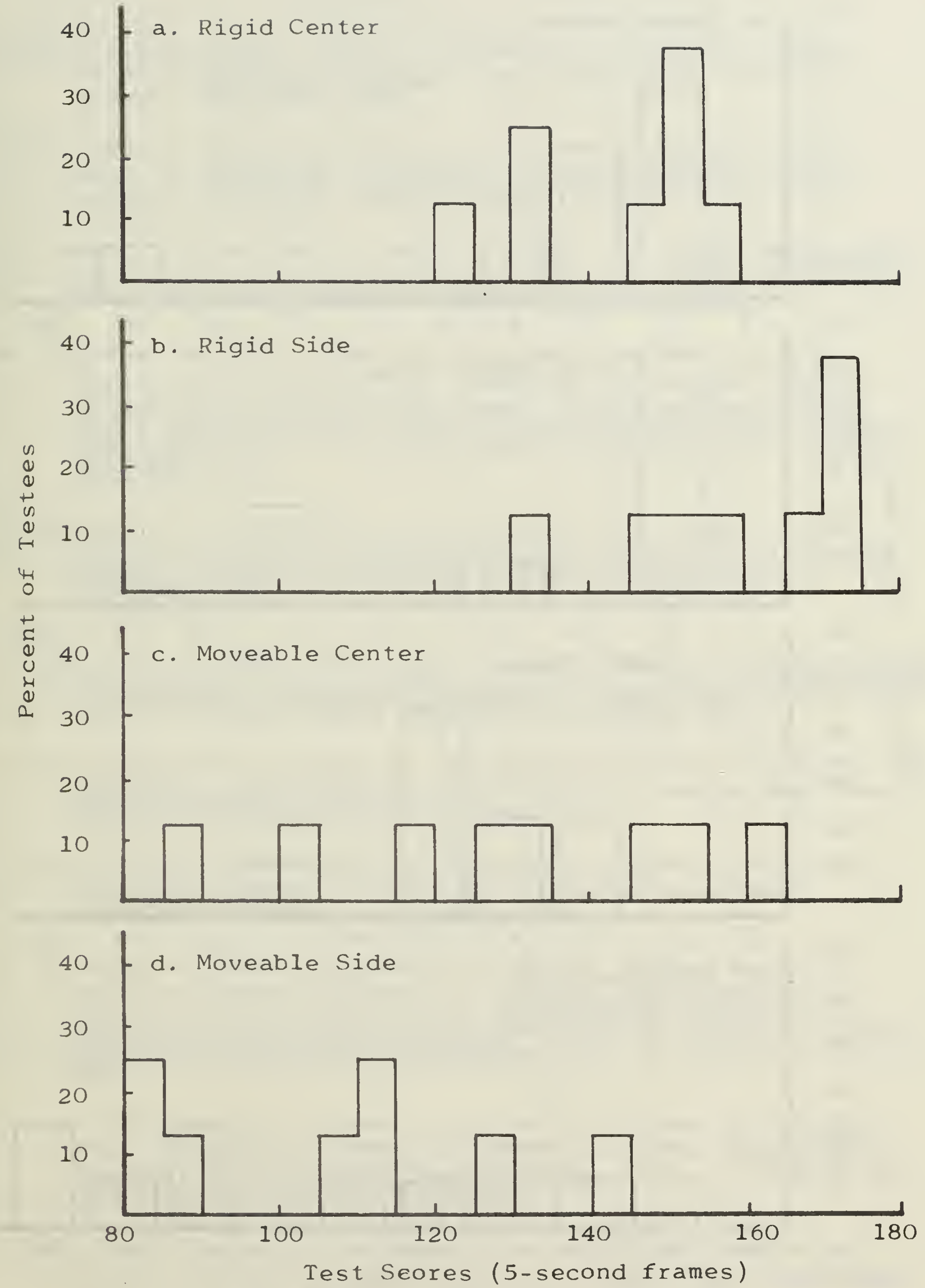

Figure D-9. Distribution of Test Scores - Non-Pilots

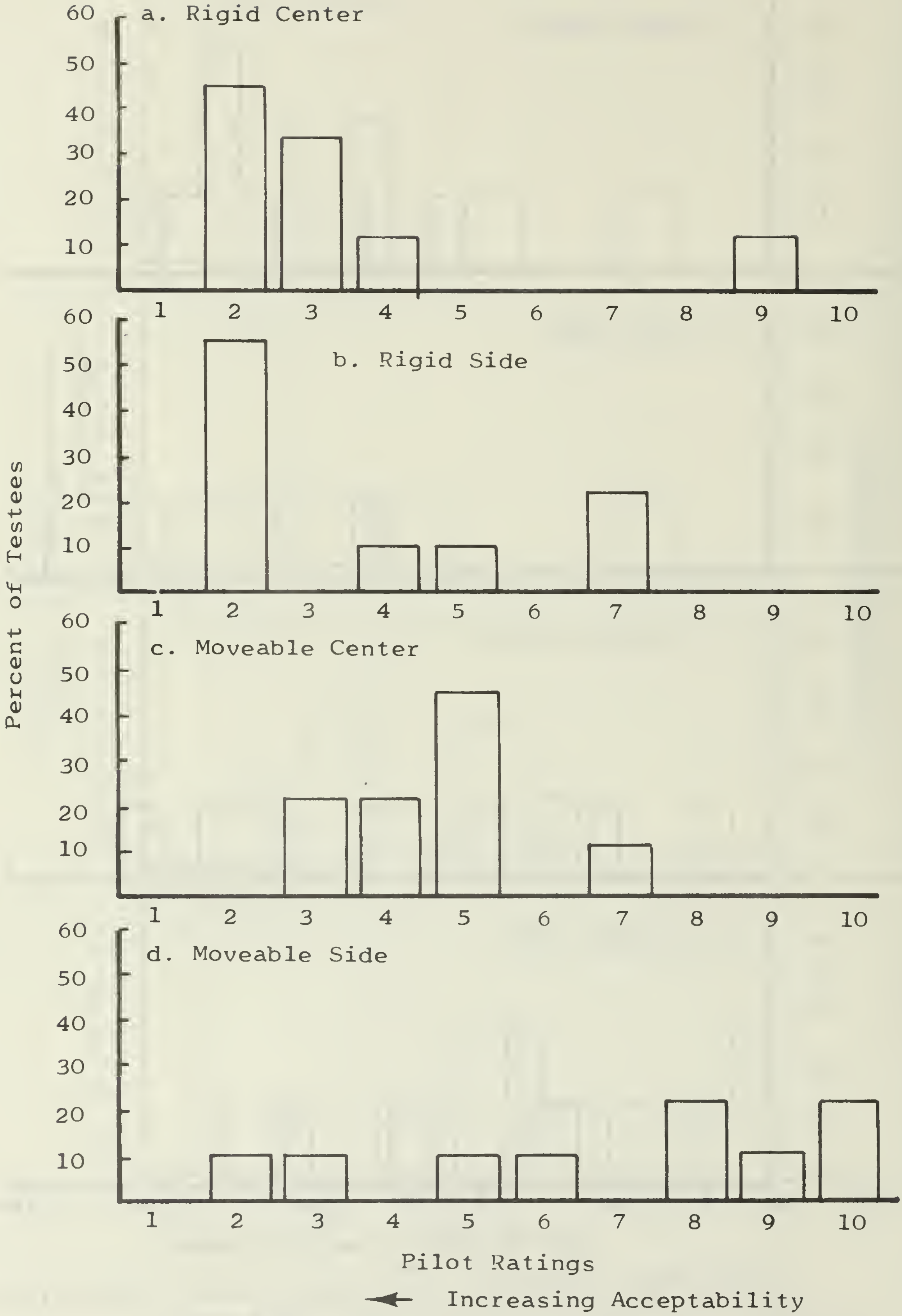

Figure D-10. Distribution of Opinions - Non-Pilots

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DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Naval Postgraduate School Monterey, California	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

A Simulator Evaluation of Pilot Performance and Acceptance of an Aircraft Rigid Cockpit Control System

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Technical Report, 1970

5. AUTHOR(S) *(First name, middle initial, last name)*

Layton, Donald M.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
15 July 1970	100	23

8a. CONTRACT OR GRANT NO. b. PROJECT NO. Air Task A31310/551/70R0050101 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) NPS-57LN70071A 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

10. DISTRIBUTION STATEMENT

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
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13. ABSTRACT

A ground-based simulator facility employing a two-axis compensatory tracking task with a random appearing signal was used to evaluate the performance of one hundred five pilot and non-pilot test subjects using four separate control sticks -- two moveable and two rigid. Pilot acceptance of the rigid cockpit controllers was determined by comparing individual pilot ratings of the sticks. In general, in both performance and opinion, the rigid systems were found to be superior to their moveable counterparts. Steps were taken to avoid errors due to pilot bias, learning, fatigue, or adaptation. The results obtained are subject to several test limitations, including the low stick-force levels employed the lack of aircraft vibration effects, and the realism of the simulation.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Simulator						
Aircraft Controls						
Human Factors						
Side-arm Controllers						

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S/N 0101-807-6821

A-31409